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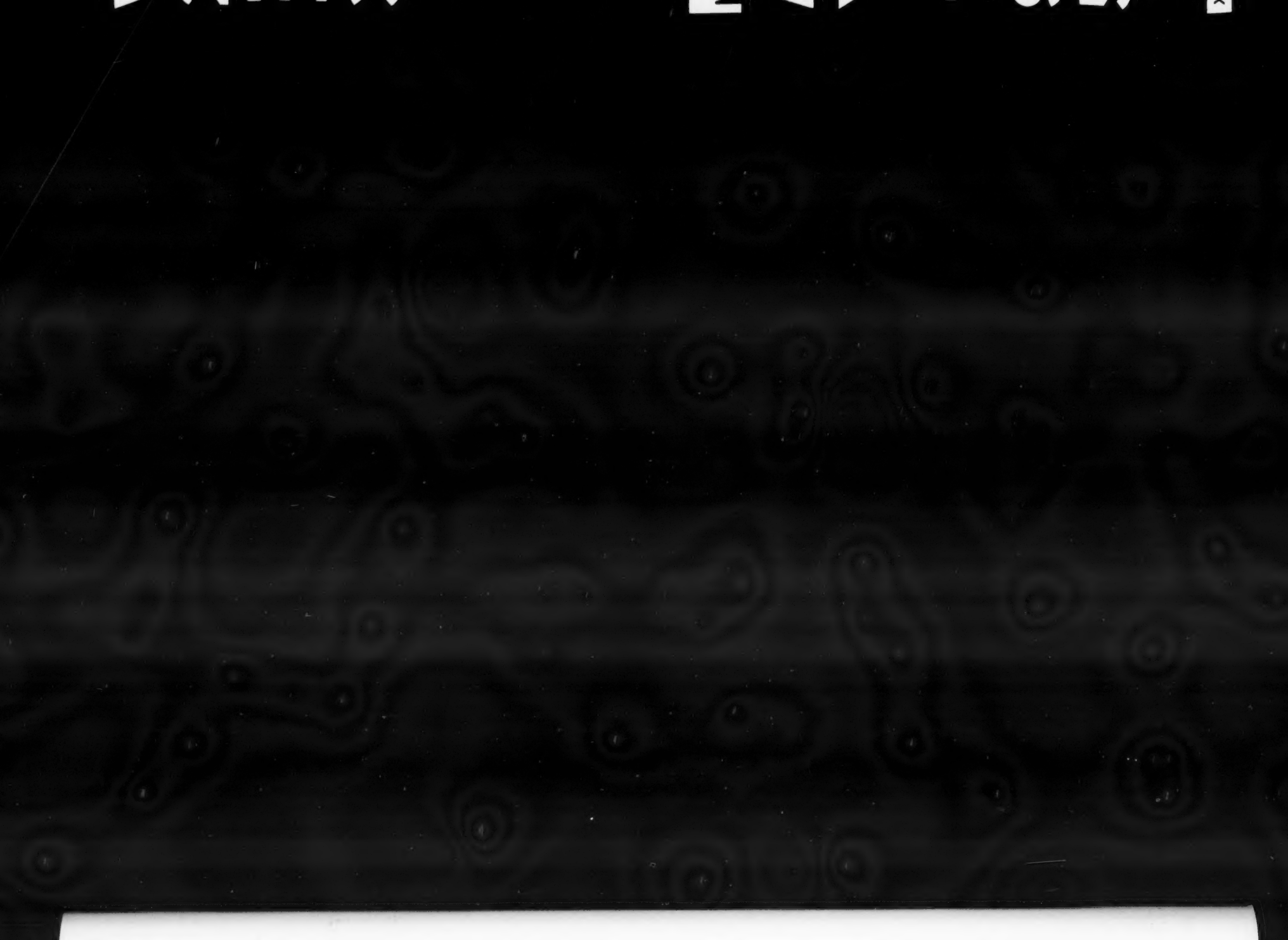

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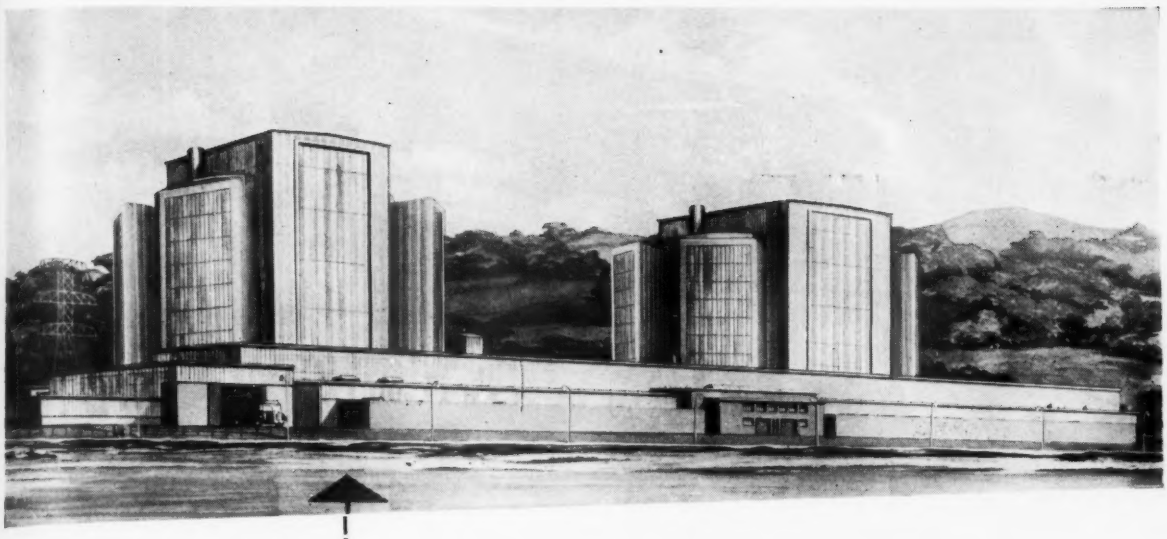

For the South of Scotland Electricity Board

The full resources of the Group are being brought to bear on the construction of a 320 MW nuclear power station.

For the United Kingdom Atomic Energy Authority

The Motherwell Bridge & Engineering Company Ltd. (a member of the Group) is building at Dounreay, Scotland, the reactor-containing sphere for the world's first fast breeder reactor. The G.E.C. is installing the electrical generating plant.

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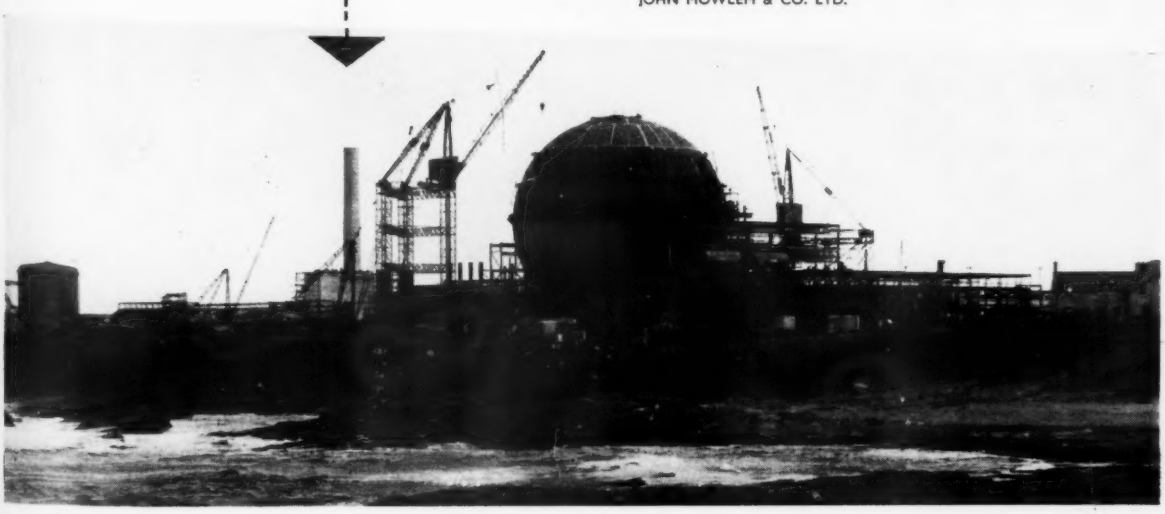

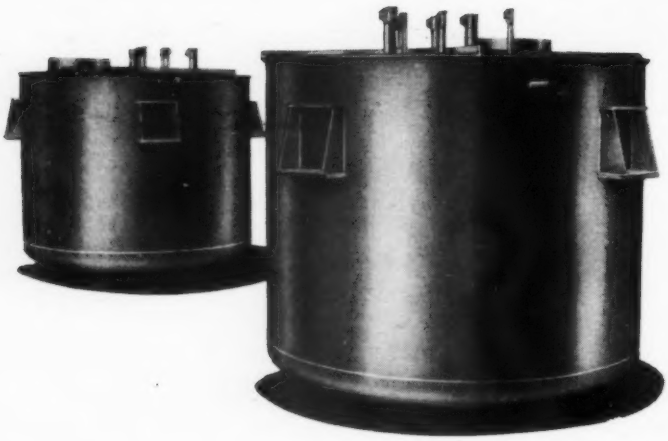

ILLUSTRATED:
(left) Stainless Steel Monitor Tanks for U.K.A.E.A.

(below) Stainless Steel Vessel for U.K.A.E.A.

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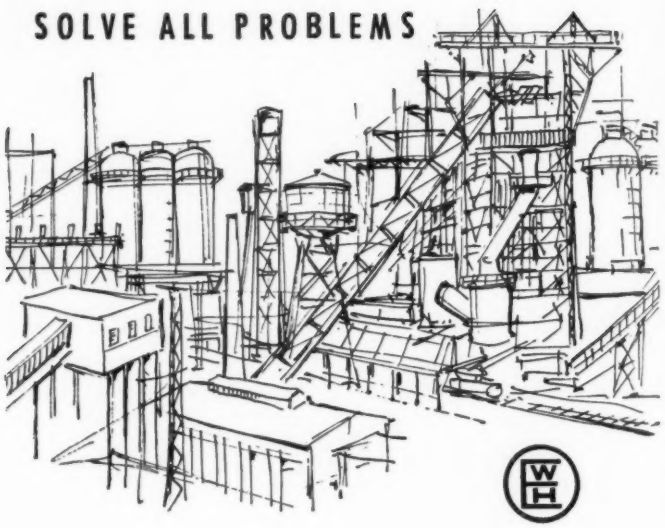

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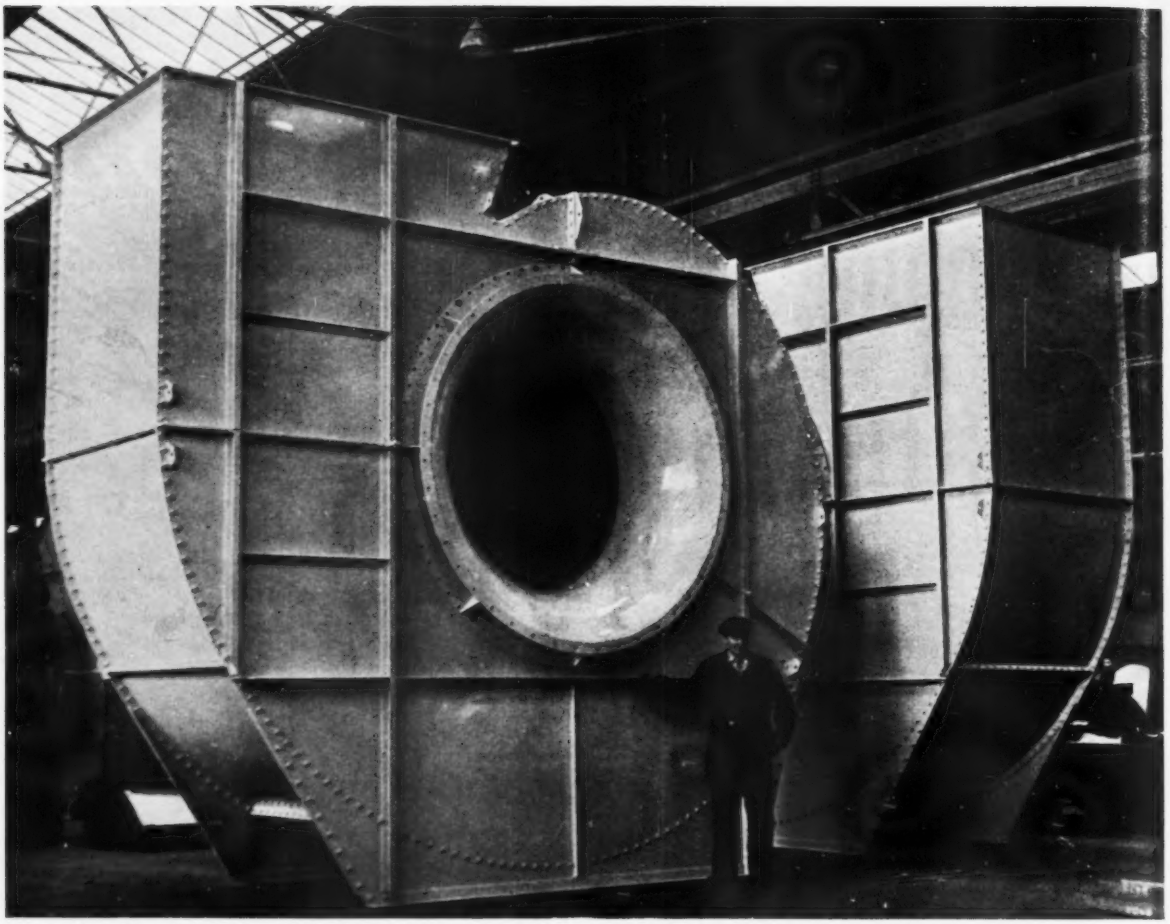

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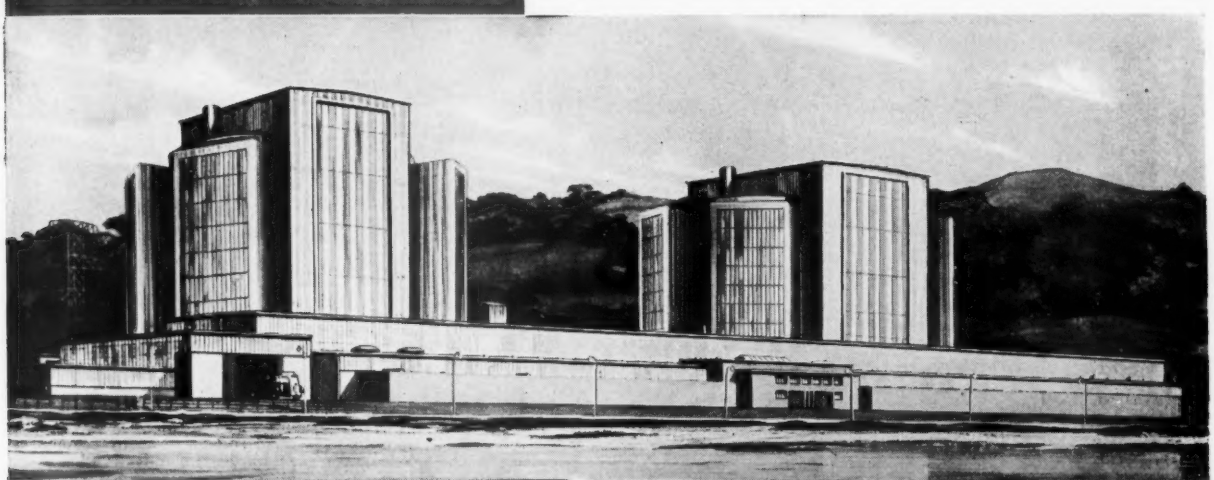

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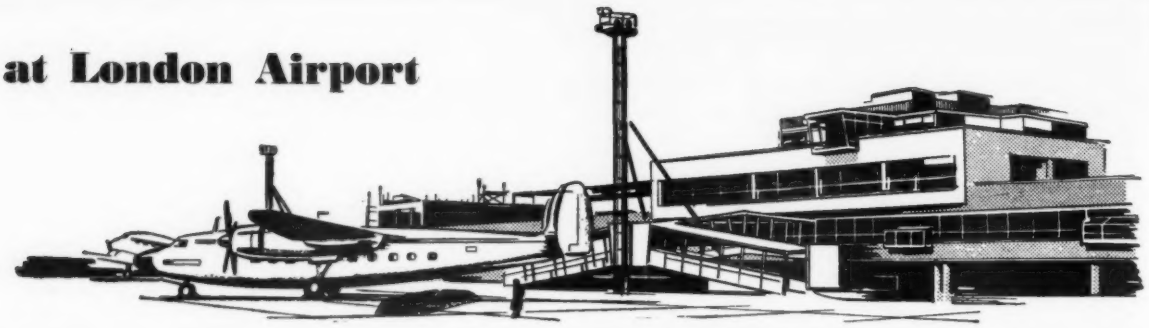

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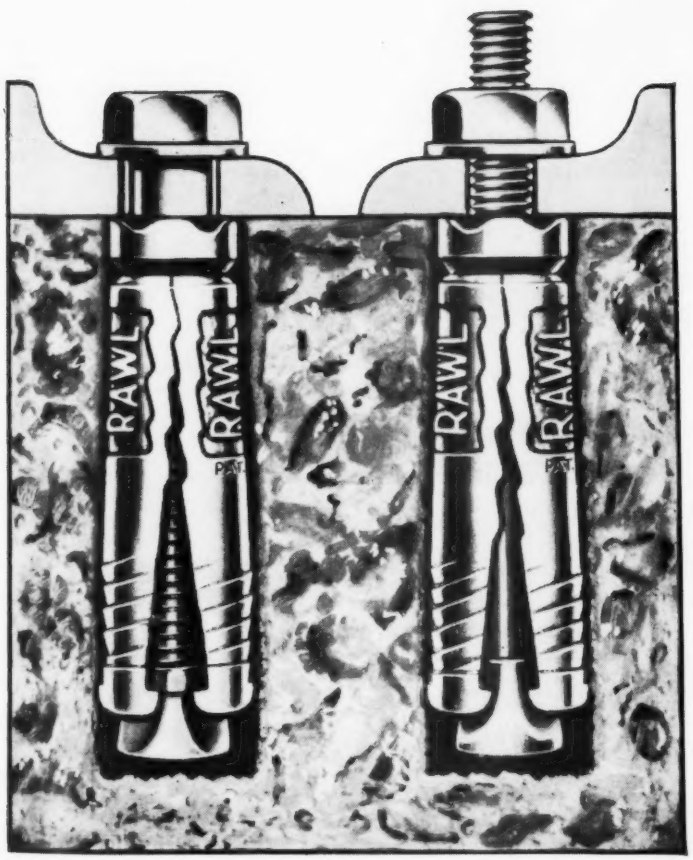

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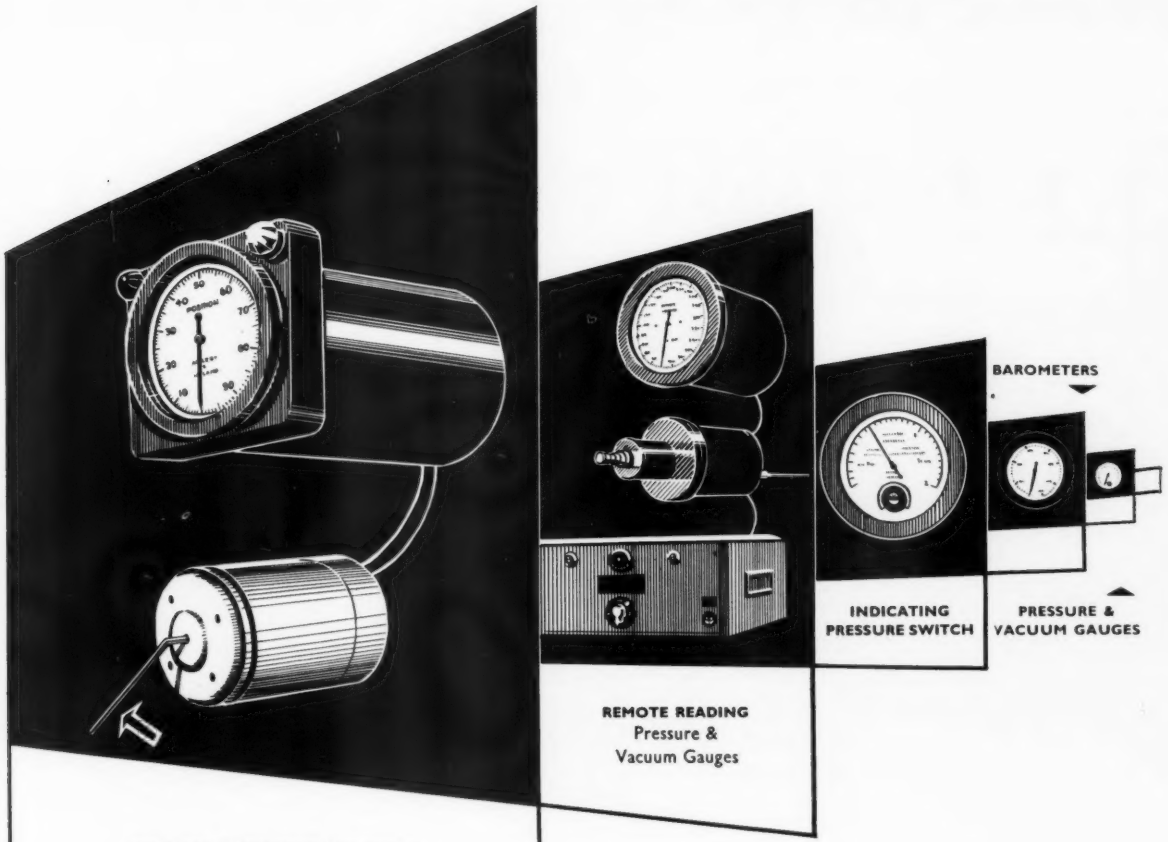

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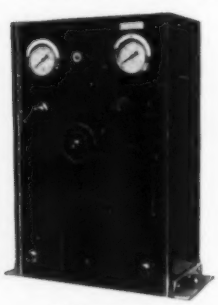

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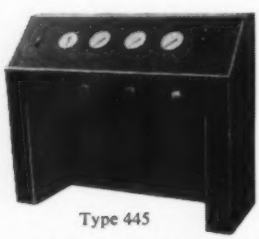

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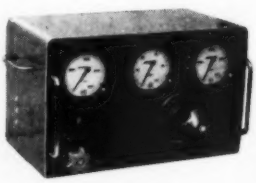

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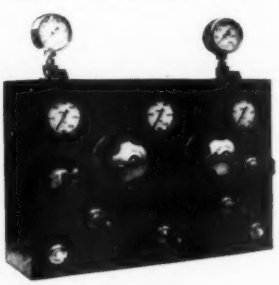

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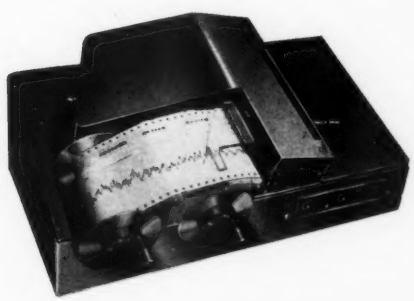

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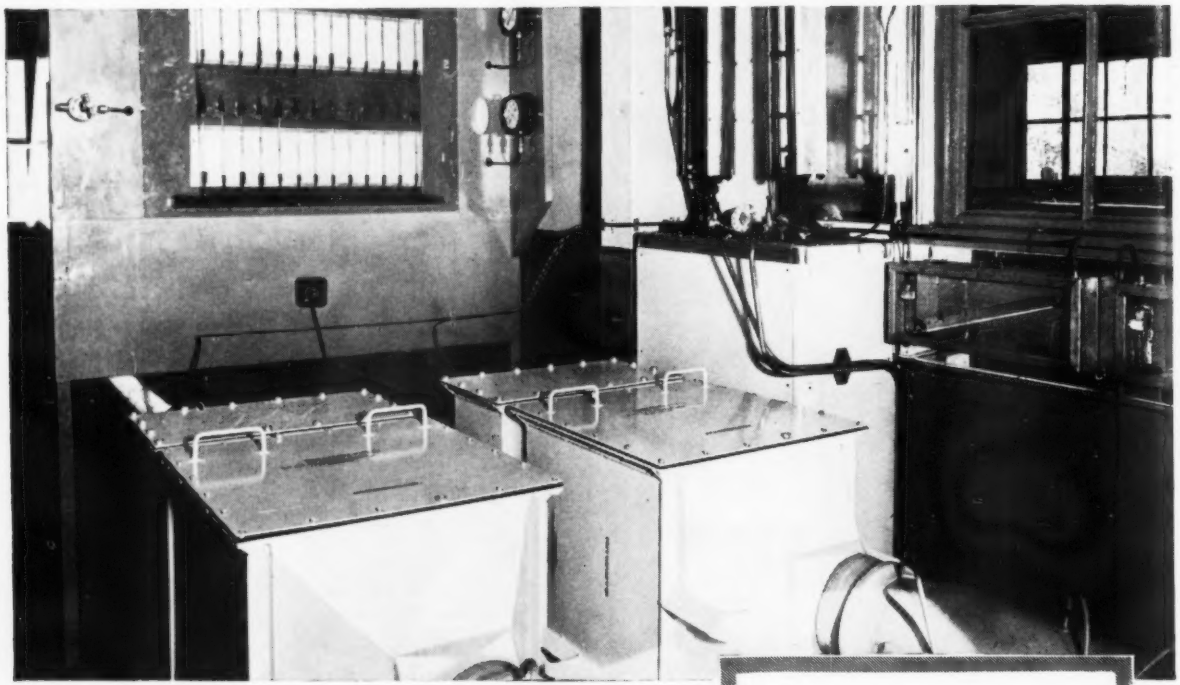

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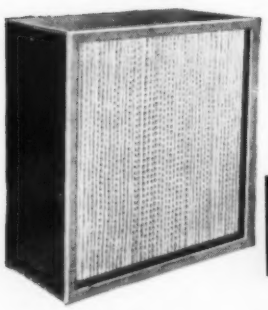

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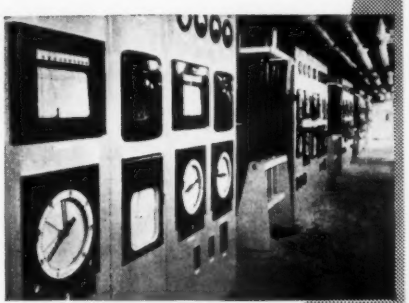

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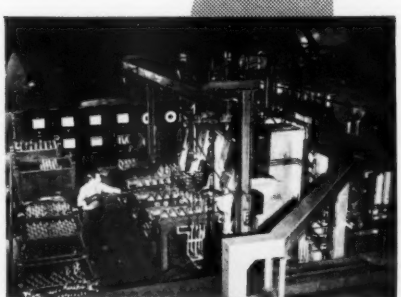

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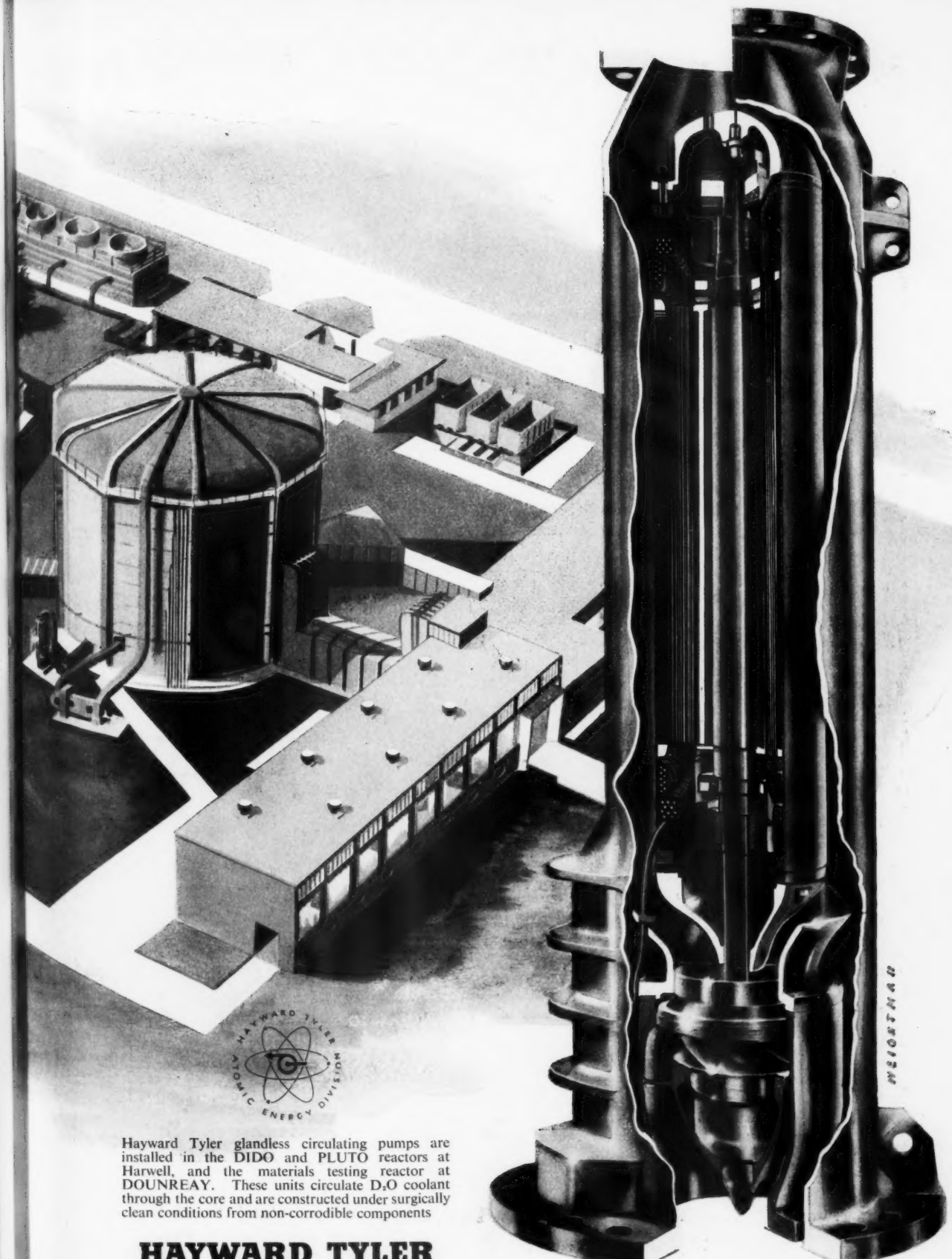

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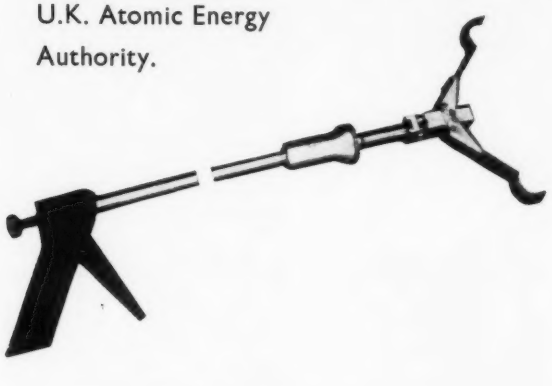

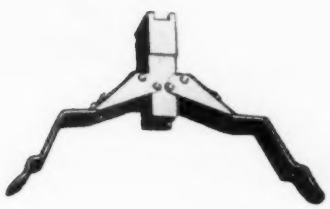

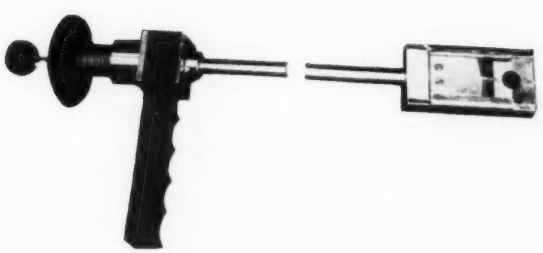

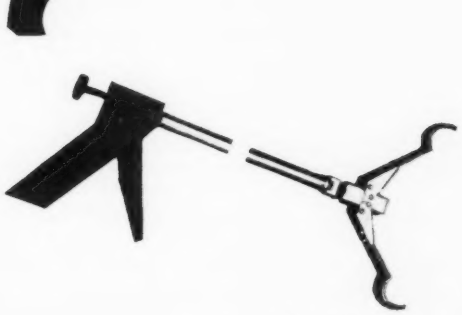

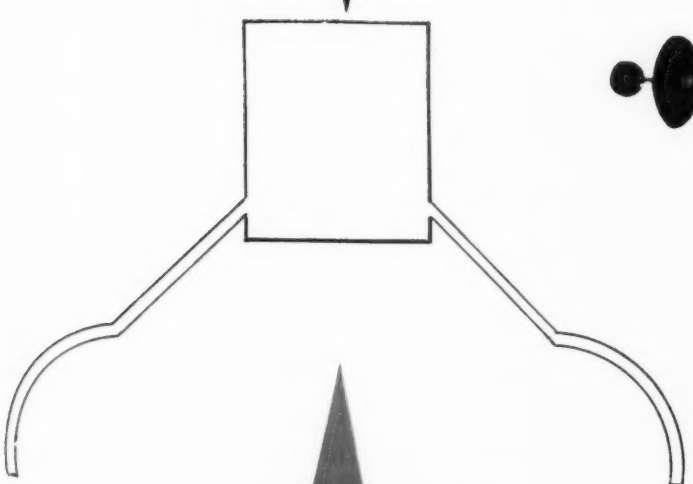

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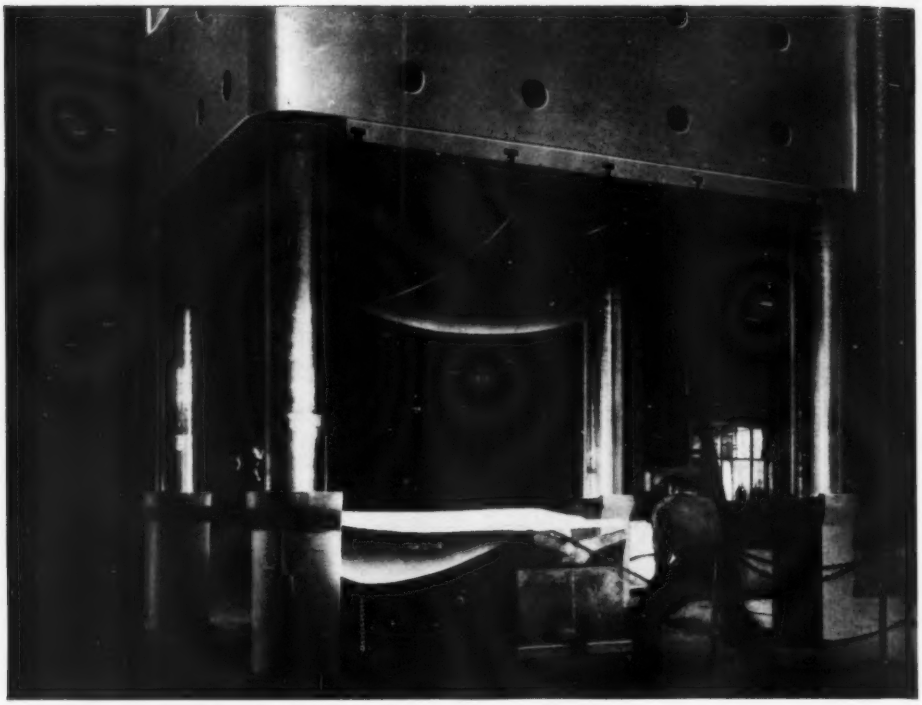

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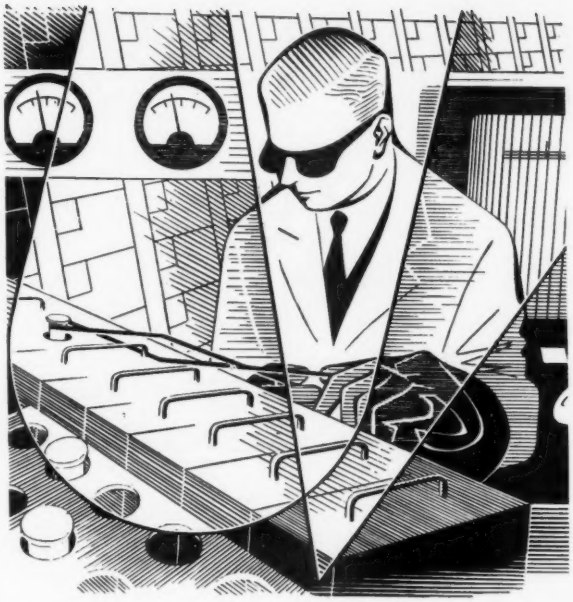

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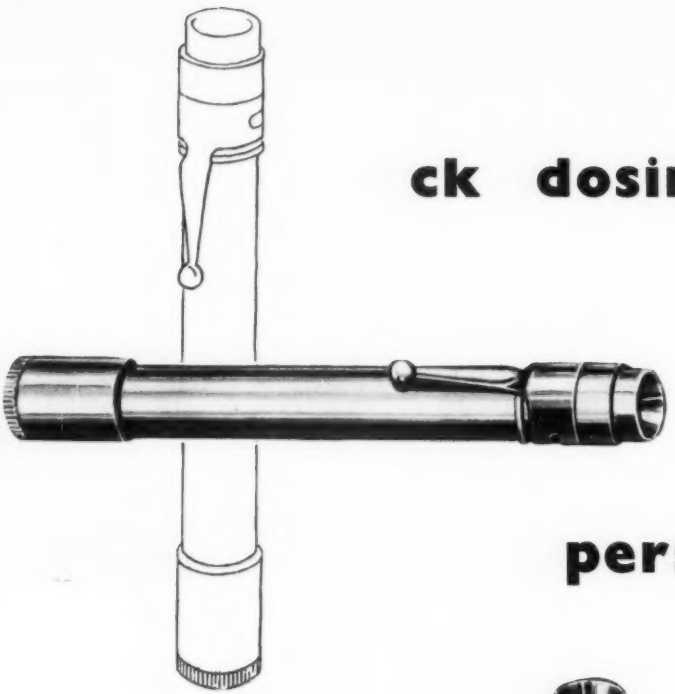

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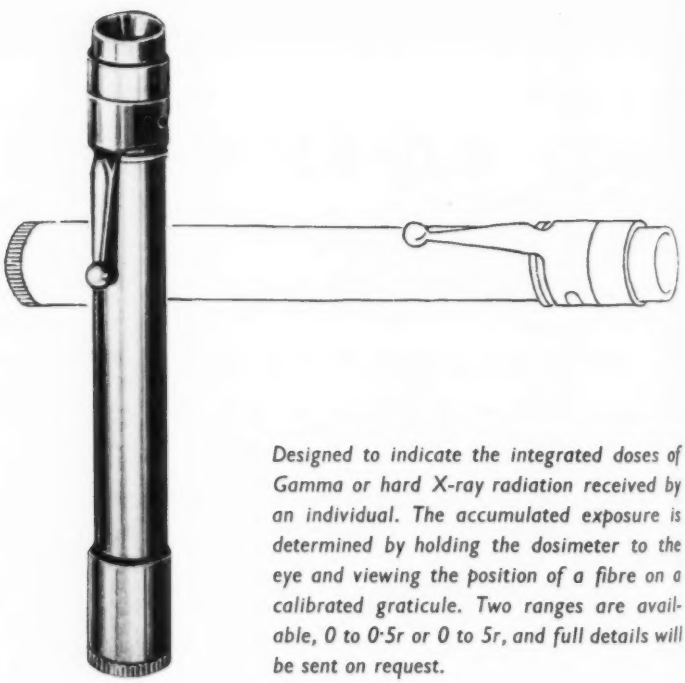

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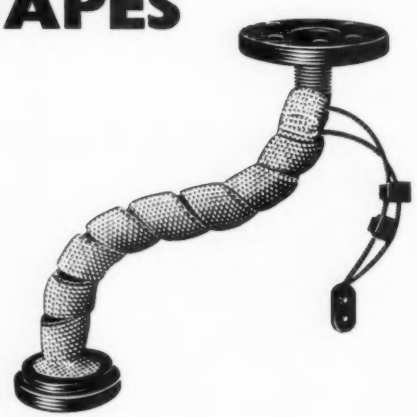

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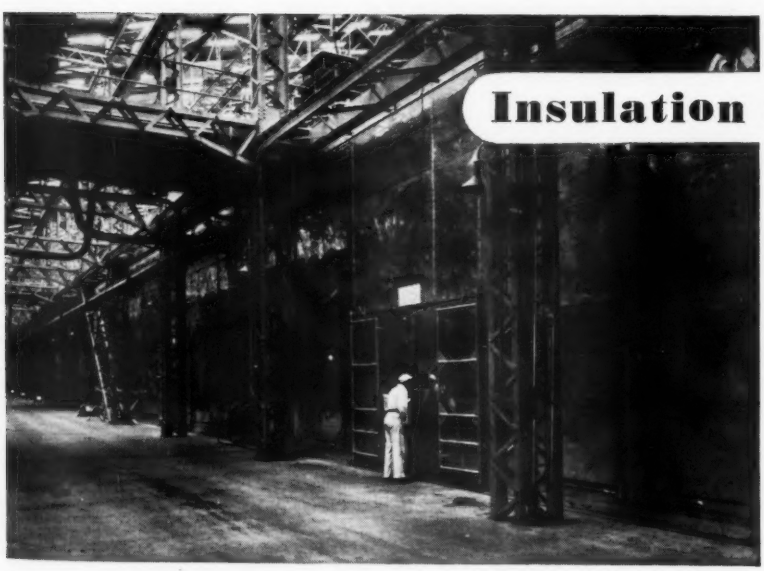

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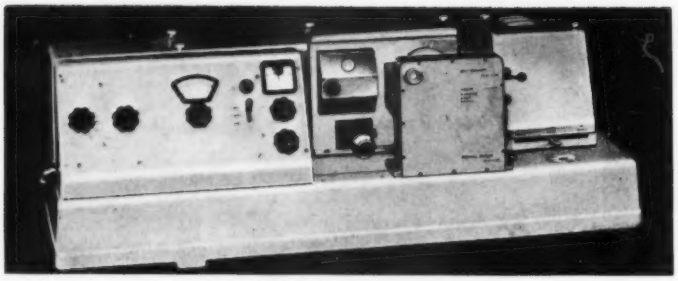

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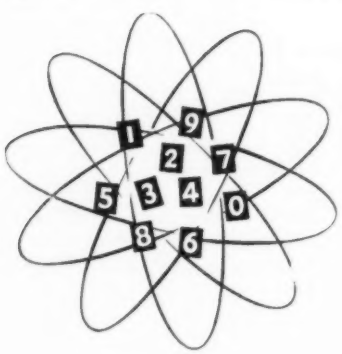

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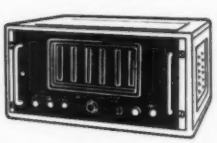

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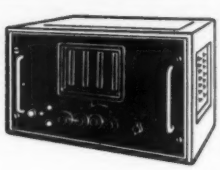

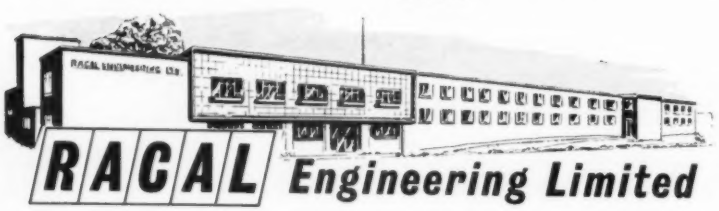

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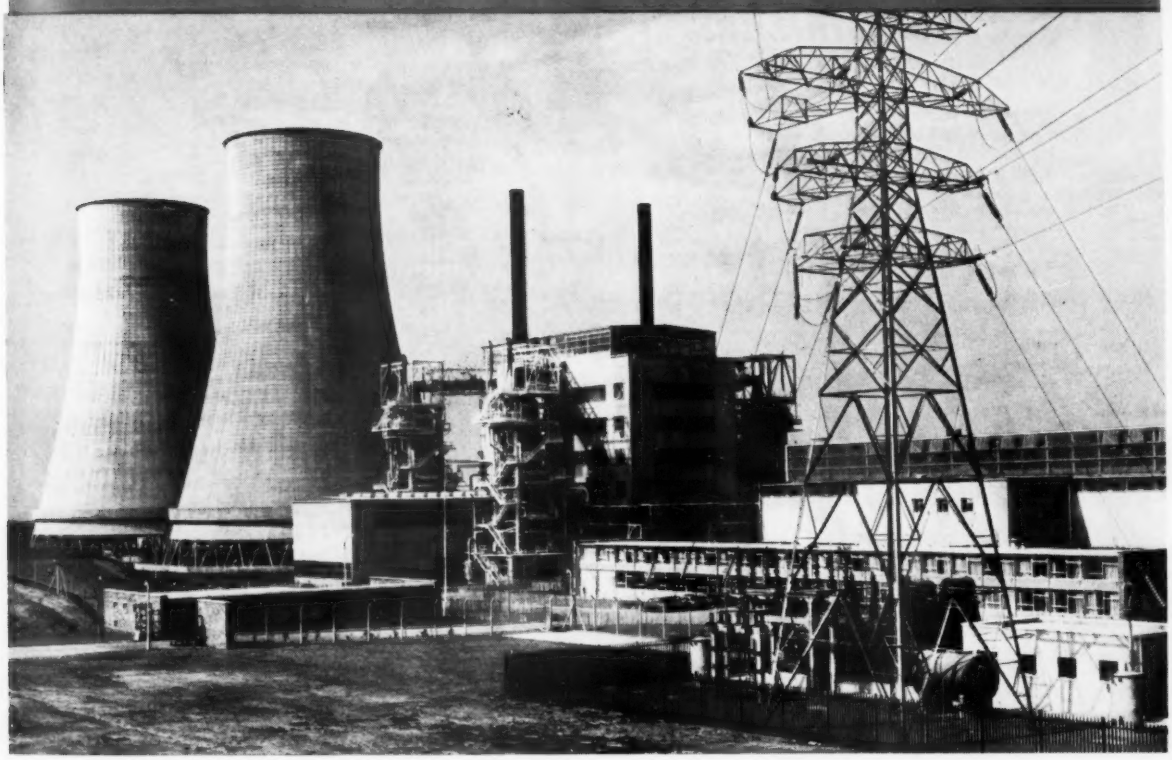

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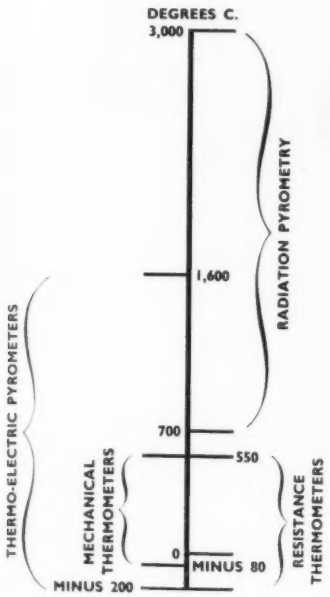

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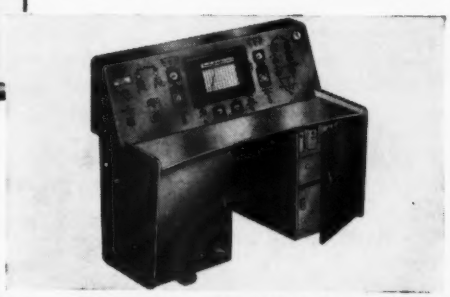

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output transistor OC72

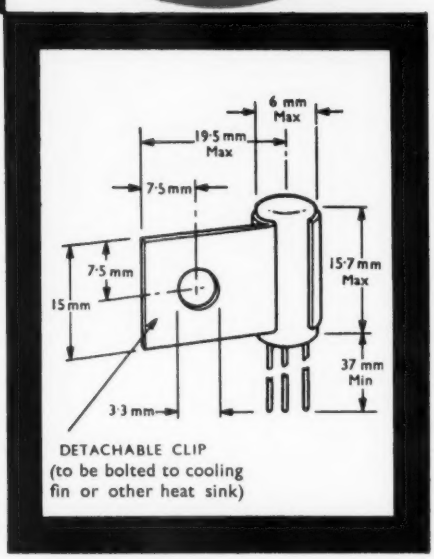
One of the most recent additions to the Mullard range of junction transistors is the OC72. Two of these transistors in class "B" push-pull will provide an audio output of 250 milliwatts with an H.T. supply of only 4.5 to 6 volts. The current gain of the OC72 is largely independent of collector current, so ensuring a high degree of linearity at the large peak current found in class "B" operation.

A heat sink can be used with the OC72 for those instances where it may be preferred to obtain an increased output at the expense of a slight increase in size.

In addition to its use in linear transistor amplifiers, the OC72—with its peak current of ¼ amp—can be employed in computing circuits, to close relays, to deliver power to small mechanisms and in many other applications where the requirements are small size, low H.T. voltage and large current pulses.

The current amplification frequency cut-off of the OC72 is not less than 350kc/s. Operated as a "flip-flop" and in the bottomed condition with an H.T. of 12 volts it will deliver in the "on" condition at least 1.2 watts.

Seven pages of data and curves on the OC72 and full information on other Mullard transistors are readily available upon request.



ABRIDGED DATA

Max. collector voltage*	32V peak	16V d.c.
Max. collector current	250mA peak	125mA average
Max. power dissipation at 45°C:		
Without heat sink	75mW	
With heat sink	100mW	
Min. cut-off frequency (in grounded base condition at 6V, I_c = 10mA)	350kc/s	

*In grounded base or in grounded emitter with a base emitter resistance of less than 1,000Ω.

CHARACTERISTICS OF MATCHED PAIRS

(Two transistors in class "B" push-pull:grounded emitter)

Output (without heat sink)	275mW
H.T. voltage	6V
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Load impedance (collector to collector)	140Ω
Full drive collector current (peak)	125mA
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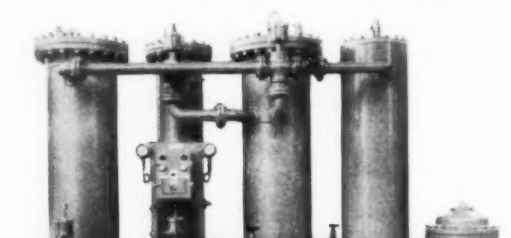

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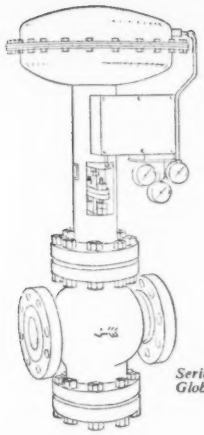

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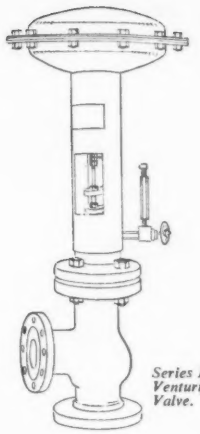

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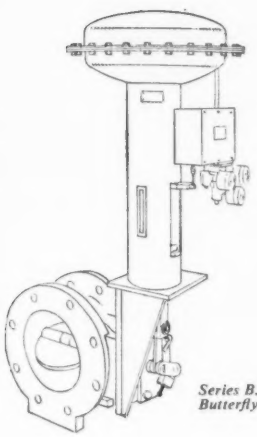

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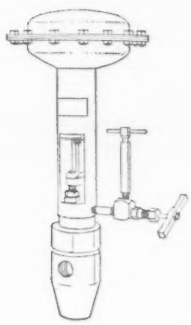

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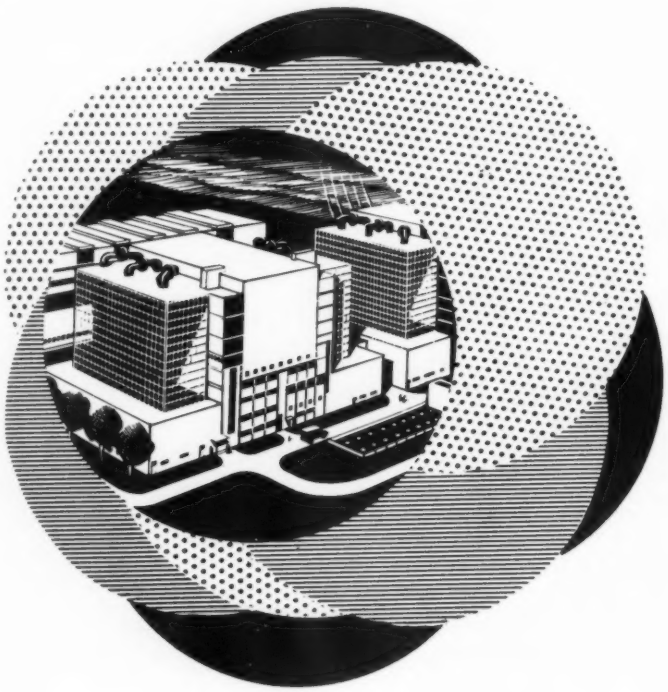

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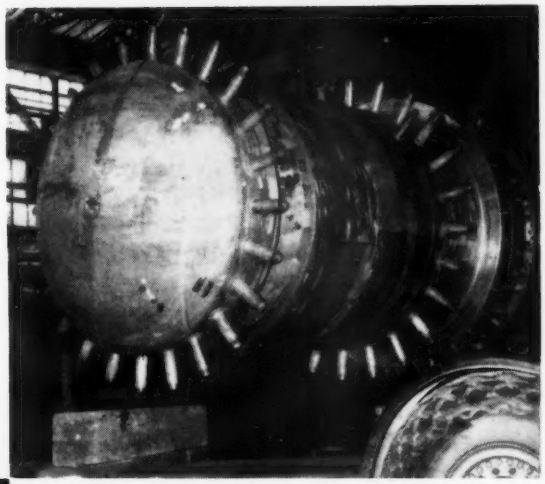

Said to be the most complicated piece of stainless steel fabrication in the world, this 45 ton vessel is for the UKAEA's fast breeder reactor at Dounreay in the North of Scotland (see Worldview story)

Nuclear Power
The journal of British nuclear engineering

Leader	169
Worldview	171
Production of uranium metal powder, Bellamy & Buddery	175
Instruments, Electronic & Automation Exhibition	180
Gas-cooled reactor fin design, Fortescue	188
The homogeneous aqueous reactor, Hurst, Wells & Newby	193
Bremsstrahlung thickness gauge for hot strip mill	196
Equipment	198
Reactor Physics—12, Hill	201
Books	206
Companies	208
Names in the News, Institutions	210
Research Reports, Programme	211
Patents	212
Index to advertisers	facing inside back cover

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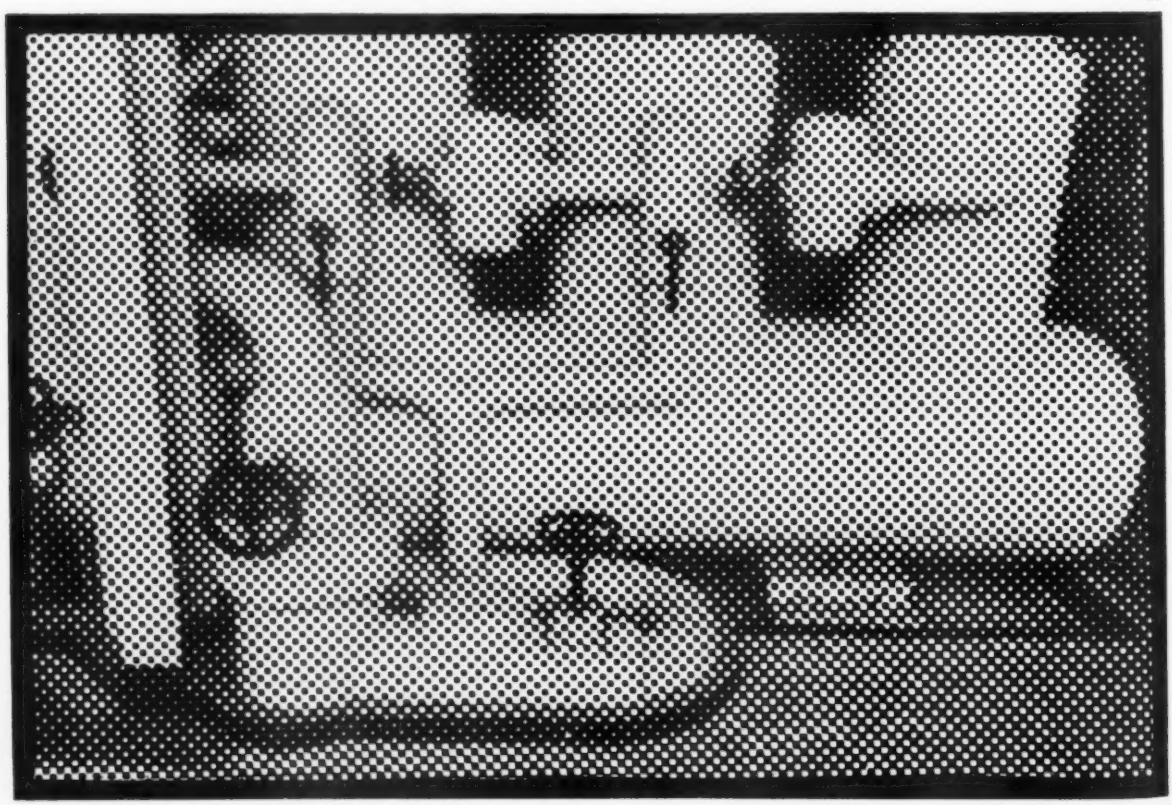

Nuclear Power
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING
MAY 1957 VOLUME 2 NUMBER 13

Euratom and us

THE TIME is rapidly approaching when Britain will have to define her position with regard to Euratom. True, the European Atomic Community will not formally come into being until January 1, 1958—and then only if the six signatories to the Rome Treaty manage to obtain ratification from their Parliaments by that time—but in European industrial circles the idea has already caught the imagination and there seems little doubt now that a viable and closely-knit organization will emerge.

While the 'three wise men of Euratom' spoke highly of the help and advice they received from the authorities and firms during their visit here in March, it is no secret that in Luxemburg there is acute disappointment that Britain's position is in fact only 'all aid short of actual participation'.

The dilemma confronting the United Kingdom is really one of timing rather than of principle. It is now widely recognized—and the realities of the situation are becoming more apparent every day—that in the fullness of time we shall have to associate with Euratom in some form or other. The question is simply 'when?' and there is a good case for making the answer 'now!' If we announced our intention at the present time to conclude an agreement with Euratom, or even actually to join it, we should be doing so as the undisputed leaders in atomic energy in Europe and this would command respect and confidence. If, on the other hand, we leave it until the Community is formed ('The Common Market in nuclear materials will seek to . . . apply a common tariff to third countries' *Clause IX of the Treaty*) the conclusion would be inescapable that we had been forced to.

It is argued that if we go with Euratom we shall sacrifice precious knowhow and experience accumulated over the last ten years when we had to go it alone. This is simply not true: we should be paid for it. But even if it were, what would the 'sacrifice' really amount to? We have indeed a lead over the rest of Europe but it is nothing like a ten years' advantage. Since Geneva, a vast amount of material has been declassified and in addition the Europeans have been promised access to classified American data and aid on a massive scale. Europe has some of the finest engineers and scientists in the world—consider what Louis Armand has done with French Railways—and when they get started in earnest on atomic energy it cannot take them long to reduce our lead to vanishing point. The French indeed have already come a long way. Frankly then, Europe, with massive American aid is ganging up on us and it might be apposite to recall the saying 'if you can't beat 'em, join 'em'.

It is also said that by joining we shall sacrifice some of our national sovereignty. This argument has lost most of its force since Suez. As the Defence White Paper made painfully clear last month, militarily at least we are already considering ourselves as Europeans. As if to underline this, it might be recalled that the Chiefs of Staff have at last withdrawn their 50-year-old objection to the Channel Tunnel!

Europe can be one of Britain's finest markets for nuclear energy goods, but only if we go about it in the right way. Until the Armand Committee has made public its report it will not be known where the Euratom countries are likely to go for their first power plants. There is a very good chance that it will be Britain, although it is believed that the wise men were very impressed with the Canadian natural-uranium heavy-water philosophy. However, once they have built a power plant, perhaps with British aid, and know how to do it, is there any guarantee that they will continue to come here if we stay outside Euratom? That is the problem that must be faced now.

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UNITED KINGDOM

PM now responsible for atom

With the dramatic resignation on March 29 of Lord Salisbury, Lord President of the Council, over his disagreement with the Government on its Cyprus policy, overall control of atomic energy in Britain also changed hands. The new Lord President is the Earl of Home but responsibility for atomic energy was transferred by an Order in Council to the Prime Minister.

With the present uncertainty as to the future of nuclear weapon tests it is probable that Mr Macmillan felt it advantageous at the present time, when acute political controversy might be expected, to have the Government's chief spokesman on the subject sitting in the House of Commons.

Hawker-Sid to take over Brush?

Big industrial news last month was the reported take-over bid for the Brush Group by the Hawker Siddeley Group. Worth over £M6 the H-S offer is for the whole of Brush's issued share capital on a share exchange basis. In a statement recommending the take over to his stockholders, Brush chairman Geoffrey Eley said that since he joined the Group three years ago he had been conscious of its great potentialities but also of the check on its growth by the company's under-capitalization.

The deal will have important repercussions on the British nuclear industry. With the recent defence cuts and the switchover to missiles from manned military aircraft, Hawker Siddeley are obviously looking ahead to nuclear energy and of course have already formed a subsidiary—Hawker Siddeley Nuclear Power Co Ltd—which is at present engaged on a study of liquid-metal-fuelled reactor systems. Commenting on this last month Hawker Siddeley director Sir Roy Dobson said the Group was in an era of diversification and expansion. In addition to the Brush deal, they had several other large projects in hand in Britain and in Canada. 'Details of these' added Sir Roy 'will be announced in due course.'

It has been known for some time that the Brush Group (Brush Electrical, Mirlees Bickerton & Day, National Gas and Oil Engine and Petters) have been finding the going difficult and indeed paid no ordinary dividend last year. A year ago they were joined as Technical Director by Brian L. Goodlet who, of course, was one of the moving spirits behind the Calder Hall power station, and it was widely supposed at the time that Brush were going into nuclear power. Evidently their financial situation has prevented or delayed their plans and the new deal if it goes through should provide an exceptionally powerful new British nuclear group.

Reactor power at 1d a unit

Pressurized water reactors similar to, but larger than, APPR (see this *Worldview*) can be built in Britain for as little as £150/kW with running costs of 1d to 1½d a unit, according to Ambrose Congreve, chairman of Humphreys & Glasgow Ltd who have an agreement with Alco Products Inc of Schenectady to market this type of reactor in Britain. Where the British agreement was announced (*Worldview*, March) figures of £200 per kW installed and running costs of 1½—2d a unit were mentioned. These were based on American figures but detailed study of British manufacturing costs had now shown that substantial reductions were possible. Furthermore, the revised figures were for a completely new reactor: repeat orders might be installed for as little as £134 per kW.

A spokesman for Humphreys and Glasgow said the company had already received enquiries from all over the world and they were convinced that already the Alco reactor could show considerable financial savings over conventional plant in many areas.

Nuclear ships planned

The Birkenhead shipbuilding firm, Cammell Laird, recently announced plans to design atomic-powered tankers. A spokesman for the company said 'Men are already at work in our development design section and in due course we hope to be in a position to build atomic-powered ships. Our plans will materialize, but it is a question of how soon.' The company believe that they are one of the first British shipbuilding firms to enter this field.

Dounreay vessel arrives

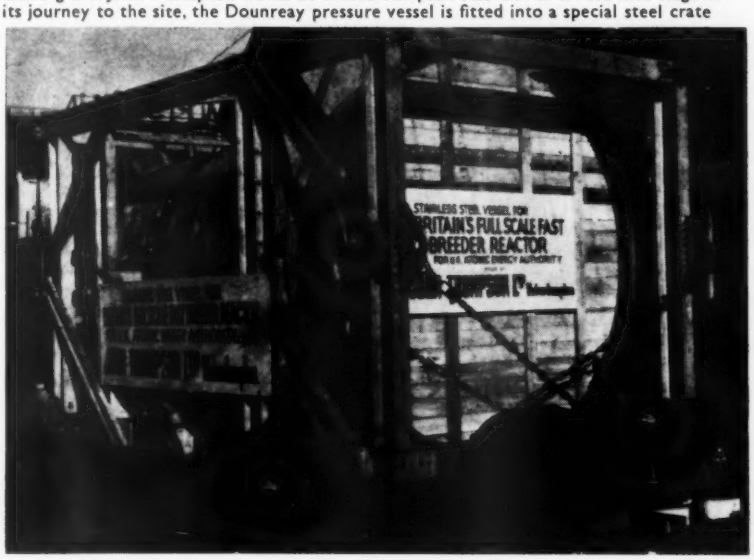
The 30-ton stainless steel container for Britain's first full-scale fast-breeder reactor left John Thompson's works at Wolverhampton for Dounreay, on the North coast of Scotland, on April 6, where it will be installed along with liquid-metal heat exchange systems and boiler plant manufactured by John Thompson for the Atomic Energy Authority.

To by-pass bridges of limited capacity en route, the container travelled by road to Middlesbrough, by ship to Wick, and again by road to Dounreay. Even so, it had to cross one bridge in Scotland with only six inches clearance either side.

This container is probably the most complicated stainless steel vessel ever fabricated anywhere in the world. It has taken eighteen months to build. While its overall dimensions are some 20 by 14 feet, the complex control rod tubes, instrument pipes, rotating shields and inner components of the vessel have been positioned and welded to thousandths of an inch. More than 3,500 X-ray negatives have been taken to ensure that every welded joint is absolutely leak-proof.

For safe transportation the vessel was carried in a specially fabricated steel cradle which had previously been tested by using a steel and concrete 'mock-up' of the same general dimensions, weight and centre of gravity as the vessel itself.

Leaving the John Thompson works at Wolverhampton last month on the first stage of its journey to the site, the Dounreay pressure vessel is fitted into a special steel crate



On arrival at Middlesbrough, the cradle, complete with vessel, was loaded aboard the M/V *River Fisher* by use of sheer legs at Dent's Wharf, under arrangements made by shipping agents H. P. Marshall and Company, of Middlesbrough.

Shoring-up and loading on the ship was so arranged that at Wick the load was jacked-up, skids inserted, and the cradle drawn off on to transport on the quayside when the tide was at the required level.

On site at Dounreay, the reactor vessel will be placed in position in the vast concrete vault, some six feet thick, which acts as a biological shield for the reactor and all the primary liquid-metal circuits taking heat from the reactor. This vault is, in turn, enclosed within the huge steel sphere 135ft in diameter, which has become familiar in illustrations of this Atomic Energy Authority nuclear station.

For many months John Thompson construction men have been at work within the vault, assembling and welding the complicated and close-packed stainless steel circuits which will be connected to the reactor vessel when it is placed in position.

AEA names new contracts head

The Atomic Energy Authority last month announced that Mr R. A. Browning OBE, Director of Contracts is retiring shortly. He is to be succeeded by Dr F. A. Tatford, *left*, who since 1954 has been Chief Purchasing Officer at the Authority's Industrial Group Headquarters at Riseley, Lancs. Dr Tatford's London Office is at 1 Richmond Terrace, Whitehall, SW1.

NIRNS to build at Harwell

The first particle accelerator for the newly-formed National Institute for Research in Nuclear Science will be built on a site adjacent to Harwell, subject planning consent. The final decision to proceed with design and construction will not be made until precise specifications for the machine have been fixed.

The site chosen for the accelerator does not imply that all the Institute's facilities will be Harwell, and at present this seems unlikely. The AEA have however stated that they hope to make certain AERE facilities available to the Institute.

CANADA

Rethinking NPD

Work on Canada's NPD heavy water power reactor experiment at Des Joachims has been suspended temporarily because major design changes are to be made. A statement made jointly last month in Ottawa by Atomic Energy of Canada, Ontario Hydro and Canadian General Electric said important technological advances recently made are to be incorporated in NPD. The basic design of the reactor will not be affected and the power output will still be 20 MW. Site work started last autumn and so far only foundations have been completed. NPD will not now be ready before 1960.

What the changes are were not mentioned in the statement, but speaking in Philadelphia in March at the *Fifth Conference on Atomic Energy in Industry*, AECL's vice-president W. B. Lewis announced that Chalk River had now decided that corrosion-resistant uranium oxide made a much better fuel element than metal, and they intended to switch to it for their heavy water power reactors. Dr Lewis also mentioned a new design philosophy of horizontal channels through the heavy water tank with slugs inserted one end and discharged from the other. It seems very probable that NPD will now have oxide elements but a switch to horizontal channels would obviously mean scrapping the whole original concept.

Nuclear power in Canada, went on Dr Lewis, was up against very cheap hydro-electricity and could only compete if the cost could be brought below 6 mills/unit. Six years ago Chalk River did not see how this could be done but now it seemed 'just possible.'

FRANCE

Diffusion plant in new 5-year plan

France's second atomic five-year plan comprises power stations, a diffusion plant and a nuclear submarine. This was revealed in Paris last month by Georges Guille, Secretary of State for Atomic Energy, when he announced the new programme. The plan includes not only a great expansion of the activities of the Commissariat à l'Energie Atomique but will also involve to a much greater extent than before, both public and private industry. M. Guille also said France would associate from the start with Euratom, OEEC and the International Agency.

The CEA budget alone for the period 1957-61 would be nearly £M400. Most of this will come direct from the Government but some will be obtained for work done for other Government departments and some from other sources. The present programme of Electricité de France power stations is for a total installed capacity of 800MW by 1965, supplying 5 per cent of France's total needs and saving 2 million tons of coal a year. This, however, according to M. Guille, is now to be accelerated as a result of CEA studies. These are now to be directed towards high temperature systems and several reactor experiments are to be built so that future power policy can be more accurately determined.

Noting that in 1952 France had chosen the plutonium route for enriched fuels because U-235 was not then obtainable, M. Guille said this had enabled her to produces electricity as well, and had given her valuable experience in high fluxes and hot materials handling. Enriched uranium was however now available from America and the Government had had to decide whether to rely entirely on this or to go ahead with plans to make it herself. The conclusion had been reached that France should have her own source of supply even if the 235 cost more than the American material and a decision is to be made soon on the plant. This might be a purely French one or it might be a common enterprise with other countries. France thus intends to have her own supplies of both primary fissionable materials for her advanced reactors.

Regarding the submarine, M. Guille said it would have natural uranium pressurized water reactor (possibly he meant, heavy water). It would be purely experimental: later marine reactors would use enriched fuel. Further details on the submarine were released later by Saclay assistant director Baissas. Known only by a number yet, Q244 will displace about 5000 tons—a very large submarine. Work has already begun and the ship should be ready for sea in about 4 years.

Fusion in 20 years ?—Perrin

The information conference on *Nuclear Energy for Management* held in Paris last month by the Organization for European Economic Cooperation was from all points of view a great success. The attendance of 400 business men and industrialists from the OEEC countries showed the importance which management is now placing on understanding the basic facts of nuclear energy.

In his opening address, High Commissioner Francis Perrin of France, said that even progress on thermonuclear power was more rapid than he thought it would be, he was convinced that there would be time to amortize all the industrial fission plant at present planned in the next 15 to 20 years, before controlled fusion makes them not only obsolete but too expensive to keep in operation. He also believed that even if fission energy becomes more economical than thermal energy, coal-fired power stations would continue to operate at full capacity throughout their normal life.

The lecture which probably stimulated most discussion was that by Britain's

J. A. Jukes on *Cost Factors in Nuclear Energy*. Mr Jukes not only gave probable operating costs for the new CEA stations and compared these figures with coal-fired power stations, but indicated the likely costs of such stations in the OEEC countries.

The lectures which created the greatest interest were undoubtedly those dealing with the future programmes. From the UKAEA, J. C. C. Stewart spoke on the *United Kingdom Programme*—a very well-reasoned argument for the present British policy and her plans and hopes for the future. He showed how engineering improvements to the Calder Hall type reactor would lead to considerable reduction in capital costs and outlined the UK programme on fast breeders, pressurized water and sodium graphite reactors. Dr Amasa S. Bishop of the USAEC's Paris office spoke about the *United States Programme* and made it clear that this was motivated less by the necessity for producing nuclear kilowatts at the earliest possible date (unfortunately a necessity in the United Kingdom and many parts of Europe), than by the desire to develop the technology of somewhat advanced concepts which he thought would ultimately show greater economic promise.

The Duke at Saclay

During the Royal visit to France last month, Prince Philip visited the Centre of Nuclear Studies at Saclay. During his visit the Duke saw the CEA's latest research reactor EL 3 and the new high energy particle accelerator, both of which are now nearly complete. Here Prince Philip is seen leaving the library with High Commissioner Francis Perrin

GREECE

Recognition after 2400 years

A site on the slopes of Mount Hymettus, about 10 miles from Athens has been chosen for Greece's nuclear research centre. This will be named the Democritus laboratory after the philosopher who about 470 B.C. first propounded the idea of an ultimate particle of nature—the atom.

SOUTH AFRICA

Rhodesian U for Britain

Britain is ready to buy annually from the Federation of Rhodesia and Nyasaland, concentrates containing 500 tons of uranium oxide. This is one of the outcomes of discussions which have been going on with the UKAEA for the last year, and it was announced last month by Mr Branscombe, head of the AEA's Salisbury office. The AEA have now offered contracts covering a 10-year period from the coming into production of a mine provided the end date is not after 1972. Prices have not been announced but the AEA have given an undertaking that prices offered will be in line with current world prices. For small producers, the AEA is prepared to buy annually uranium ores containing up to 100 tons of oxide.

Linked with the offer, the UKAEA are to provide to the Federation geological and technical assistance and are even prepared in suitable cases to carry out prospecting themselves. In reply to the offers, the Federal and Territorial Governments have agreed a first option to the UK on exportable supplies of uranium.

On his return to London last month after his visit, AEA chairman Sir Edwin Plowden said although Rhodesia production would be speeded up, he doubted if it would ever approach that of the United States and other parts of the Commonwealth. So far, the only mine in production is at Mindola, near Kitwe.

South Africa tops U production

As the secrecy curtain lifted on the uranium scene recently, it revealed the Union as the world's greatest producer of uranium oxide. Reports from Johannesburg speak of a current sale of 4500 tons a year with the prospect of a rise to 6000 tons by the end of the year. Since U_3O_8 is 85 per cent metal, even the lowest figure amounts to 3800 tons of natural uranium. Last year's exports were valued at nearly £M40, current prices being quoted as between 70s and 85s per lb of oxide. Known reserves of ore are now put at over 1,100 million tons with uranium oxide content of 370,000 tons. This compares with the US 150,000 tons and Canada's 237,000 tons of oxide.

SPAIN

Atomic group set up

The formation of a big nuclear energy group was announced last month in Madrid. Known as Tecnatom SA, with offices at Barquillo 1, Madrid, the group has net assets worth 8000M pesetas. Heading Tecnatom is the Banco Urquijo, with members representing electrical, chemical, metallurgical and engineering interests.

The new company plans to develop atomic energy for industrial purposes in Spain and is already in touch with foreign nuclear energy companies. Its services will be at the disposal of the Junta de Energía Nuclear and Spanish industry. One of its first tasks is to draw up an extensive training programme for its personnel.

SWEDEN

Nuclear pumps from Britain

The British firm Hayward Tyler & Co Ltd of Luton are to supply six glandless pumps for AB Atomenegi's first power reactor. Worth about £50,000 the consignment will consist of four 250 h.p. pumps, which will handle the main heavy water circulation through the core, and two of 60 h.p. for the D_2O moderator. The pumps are of Hayward Tyler's well-known submersible type and will be entirely in stainless steel. The order was placed through AB de Lavals Angturbin.

Tax to build A-plants

The Government last month announced a special tax to raise money for nuclear power plants. This will be levied on electricity, coal, coke, petrol, fuel oil and heating oil and will bring in over £M35 a year. Opposition to the new tax has been widely voiced.

USA

'Use plutonium!' —Libby

Economic power could be achieved even in low-cost areas by utilizing plutonium. This was stated by AEC Commissioner Willard Libby, speaking last month to the American Chemical Society in Miami. He called on American chemists to develop means of utilizing the 'enormous quantities' of plutonium now being obtained as by-product from uranium-fuelled reactors. The cost of uranium-235 was such that economic power could not be generated by burning it alone except in very high-cost fuel areas. Some dividends must be obtained and the one normally envisaged is plutonium-239.

The AEC Commissioner said the only known use for plutonium at the moment was for weapons. No country had yet developed the technology of using it for power except in a very minor way. He

went on: 'At the moment we do not know how to burn plutonium-239 to produce power, but the AEC has assumed, very justifiably on the basis of past successful experience in analogous situations, that we can and will learn to do so in time. . . . I hope the chemical profession will prove us right.'

APPR on stream

The Army Package Power Reactor (APPR) was brought up to criticality for the first time last month and was officially inaugurated on April 29. Based on an Oak Ridge design study to meet a US army requirement for a reactor capable of shipment by air to remote areas. APPR is situated at Fort Belvoir, Va, just outside Washington (NP, March p 104).

The reactor is of the pressurized water type fuelled by enriched uranium dioxide in stainless steel sandwich plates. A gross thermal output of 10,000 kW is obtained which produces a net electrical output of 1855 kW from a GE turboalternator set. APPR was built largely by Alco Products Inc of Schenectady, the fuel elements and control rods being made at ORNL. It will now undergo 700 hours type testing by Alco.

Reactors similar to APPR—1 but with outputs up to 25MW are to be marketed in Britain by Humphreys and Glasgow Ltd, London.

New tool for fission work

Harnessing the energy of nuclear fusion is proving difficult but potential results are worth every effort. This was asserted recently by Nobel Prize winner Dr Glenn T. Seaborg of California University speaking at a conference on nuclear power and foreign policy in San Francisco. He pointed out that hydrogen, helium and other light elements are available in almost unlimited quantities, whereas the heavy elements are limited in supply and difficult to concentrate. Speaking at Berkeley in February, Britain's Sir George Thomson said: 'The exciting and dramatic thing about this hydrogen project is that if it can be done there will be no limit to the energy that can be produced.'

In Washington a week later AEC chairman Strauss announced plans for the construction of a new research tool for fusion experiments called a 'stellarator'—a word compounded from stellar and generator. The nature of the apparatus was not revealed but evidently it will not be a pilot plant or prototype of a thermo-nuclear reactor. Its purpose is to discover means of producing and containing the extremely high temperatures required for thermo-nuclear reactions. It will be built at the Forrestral research centre at Princeton University and experiments will begin in late 1960 or 1961.

Lockheed want A-plane

The Joint Congressional Committee on Atomic Energy is satisfied with progress made towards developing a nuclear-powered airplane. This was stated after the Air Force Secretary Quarles, had outlined developments to the Research and Development sub-committee last month. The programme has definite objectives and dates, and administrative improvements are being made to ensure maximum progress, but what these are, was not disclosed.

Meanwhile Robert E. Gross, chairman of Lockheed Aircraft Corporation, declared that a nuclear-powered plane could be assembled by his company in three years provided the Government gave the go ahead and a propulsion system was ready when they needed it. Referring to reports that budgetary considerations had slowed down the project Mr Gross said 'The nuclear plane must be built and unless production is started soon the country will regret the delay.'

Recently Lockheed began work on a new atomic facility in northern Georgia where the effects of radiation on aircraft components and systems will be investigated. Lockheed's Missile Systems Division is also building an atomic research facility at Palo Alto.

Research centre for UCC

Plans were announced last month for the construction of a nuclear research centre in Sterling Forest, forty miles from New York, by Union Carbide and Carbon Corporation. Major site facilities will include a 5MW pool reactor. The core will be made up of 25 fuel assemblies each consisting of 18 uranium-aluminium plates. The fuel charge will be approximately 9 lb of enriched uranium, giving an average neutron flux of 3×10^{13}.

Also on the site will be a radioactive materials laboratory, connected to the reactor by an enclosed passage containing a canal by which hot materials can be transferred without removal from the shielding water. Work planned for the laboratory includes studies of chemical reprocessing of spent fuel, chemical analysis of radioactive materials and metallurgy. In addition there will be a mineral and engineering laboratory in which research will probably range from the recovery of uranium and other ores to refinement processes, and include such projects as experimental reactor fuel processing and preparation of metal-organic chemicals.

USSR

10 GeV accelerator working

The proton synchrotron at the Joint Institute for Nuclear Research at Dubna —a town on the Volga about 150 miles from Moscow—has already operated at an energy of 8300MeV. It is designed eventually to reach 10,000MeV. This was announced last month in a statement in *Pravda* signed by JINR director Dmitri Blokhintsev and the two deputy directors Vaclar Votruba (Czechoslovakia) and Marian Donysz (Poland). Said to be the largest accelerator in the world, the Dubna proton synchrotron has a 200ft diameter magnet weighing 36,000 tons. The magnetic field is kept constant to one tenth of one per cent. Professor V. Veksler, who directed the design and construction of the apparatus, said, the research and programme will include a study of the bonds and reciprocal transformations of mesons and of mesons and heavy particles. Knowledge of anti-particles may also be extended through its use. Meanwhile, according to a statement in *Izvestia* by Minister of the Electrical Engineering Industry I. T. Skidanenko, plans are afoot for a 50 GeV machine.

Isotopes aid rubber studies

Tracer techniques using radioactive carbon compounds have been used to study the biosynthesis of rubber by Academician Yevgeny Shilov. Describing his work in Moscow last month at a conference on the use of radioisotopes in industry at which British scientists were among the fifty visitors from abroad, Shilov said various tracer-bearing compounds had been introduced into the rubber-bearing plant *kok-sagyz*. After a definite period, the plants were analysed to determine whether the tracer had been assimilated into the final product and in what quantity. Results have shown that alanine, an amino acid contained in albumen, is an intermediate product in the synthesis of rubber. Carotene, an accessory substance of rubber, is formed in *kok-sagyz* from acetic acid and alanine. This is the first demonstration of alanine's part in rubber formation and may be of considerable theoretical and economic importance.

INTERNATIONAL

OEEC isotope conference

Several international scientific conferences will take place in conjunction with the atomic energy exhibition, *Het Atoom*, to be held in Amsterdam from July 1 to September 16 (*Worldview*, April). Among them will be an OEEC-sponsored conference on isotopes from June 24 to 29 and the annual meeting of the European Atomic Energy Society in September under the chairmanship of Sir John Cockcroft.

Powder metallurgy can produce shapes in fissionable material to final size if the right type of powder is available. Glove box methods used at Harwell are described.

PRODUCTION OF HIGH PURITY URANIUM POWDER

R. G. BELLAMY and J. H. BUDDERY
Metallurgy Division, AERE, Harwell

AT THE Atomic Energy Research Establishment enriched uranium or pure uranium isotopes are frequently required in the form of small fabricated shapes for purposes such as the measurement of nuclear properties or the production of prototype reactor fuel elements. These metals are exceptionally costly—far more so than platinum, for example—and the utmost efficiency is necessary, not only in their production but in their subsequent fabrication.

Powder metallurgy is among the most economical fabrication techniques; pressing to finished dimensions is possible, and it is particularly applicable to small articles. If uranium powder can be produced with reasonable efficiency, therefore, the powder route is to be preferred. Three powder production methods can be considered;

Electrolysis of fused salts

Decomposition of uranium hydride

Reduction of uranium oxide with calcium or magnesium.

The first method has a low batch efficiency, and the second invariably produces pyrophoric powder. Considerable experience has been gained at AERE with the third method[1,2].

A non-pyrophoric, approximately spherical-particled uranium powder of high purity can be produced at high extraction efficiencies by the calcium reduction of uranium dioxide; the product of magnesium reduction is at present slightly inferior, and since in producing the rarer uranium isotopes the calcium/magnesium price differential is negligible the route selected was the calcium reduction of uranium dioxide followed by compacting of the uranium powder.

Earlier workers have produced uranium powder by the calcium reduction of uranium oxides but the powder always contained unreduced oxide, lime and iron, and was frequently pyrophoric[3,4]. These disadvantages were overcome by the following technique.

A stainless steel reaction vessel of the 'bomb' type containing a prefired lime lining was charged with uranium dioxide and an excess of calcium, sealed and purged with argon. The bomb was heated until an evolution of gas showed that a reaction had occurred; on cooling a hard green 'reaction cake' consisting of uranium powder dispersed through a lime/calcium matrix was obtained. This was crushed and leached in dilute nitric or acetic acid to remove the lime and excess calcium. The uranium powder remaining was washed with nitric acid and with water, and dried under vacuum. A flowsheet is given in Fig 1. Salient features of the method are:

1. To ensure complete reduction the charge must be intimately mixed, and soaked at a high temperature after reaction.
2. Large (10-15μ) spheroidal uranium particles are produced only when reduction is complete, and the reaction takes place at the highest possible temperature.
3. Excess calcium acts as a flux in producing large spheroidal particles.
4. Nitric acid leaching requires careful pH control or uranium is dissolved; acetic acid buffers with calcium acetate at pH 5·5, and there is no attack on the uranium.
5. If the leaching temperature exceeds 30°C the uranium becomes oxidized and pyrophoric.
6. Large spheroidal uranium particles have the best hot-pressing characteristics, and compact to densities only slightly below theoretical; the discrepancy is accounted for by surface oxide films, showing that voids have been eliminated.

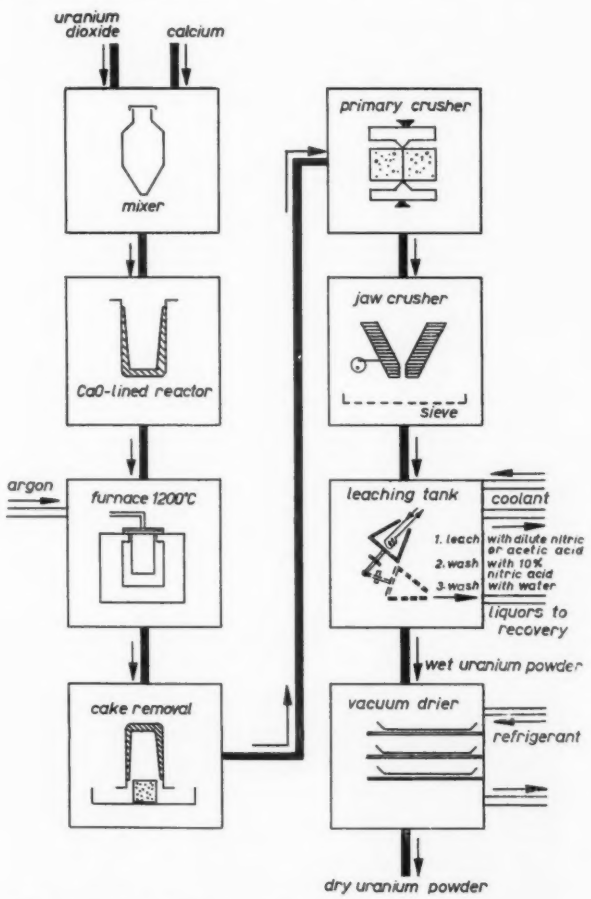


Fig 1 Flowsheet shows calcium reduction of dry uranium dioxide

The method was originally investigated on batch scales of 1-20 kg., and the best results were produced on the largest scale. For the production of the rarer isotopes a much smaller scale is necessary and while product economy is paramount, economy in the ancillary materials

is, within reason, unimportant. In addition, the uranium isotopes U-233, U-234, and U-235 are highly alpha-active, and need special handling. The alpha activity of U-233, for example, is 15,000 times that of natural uranium, and approximately one-tenth that of plutonium. Consequently U-233 compounds must be handled in a glove box. U-235 is about 150 times as alpha active as natural uranium, and while it still requires glove box handling, the precautions are less rigid. Experimental batches of uranium powder have been prepared varying from 1g to 400g in size. Generally speaking, these preparations were carried out by two techniques, covering the ranges 1g—20g and 20g—400g. The techniques differed principally in the method used for leaching. As typical examples of these techniques the preparation of uranium powder on a 15g and 350g batch scale is described. In both cases the methods were designed for glove box use, and are suitable for the preparation of either U-233 or U-235.

Development of a 15g scale technique

The development work was carried out with natural uranium dioxide supplied by the UKAEA Factory, Springfields, and with redistilled calcium prepared by ICI Ltd. Finely divided calcium was desirable for good mixing but, as the finer fractions contained more oxygen and nitrogen, the -12 $+20$ mesh BSS fraction was chosen as a compromise. Preliminary experiments with miniature versions of the large scale apparatus established that on a very small scale losses of calcium and uranium to the lime lining were considerable. Pressing the charge in a die into a firm pellet reduced contact with the lining and simplified the subsequent separation, but some lining losses still occurred, and refractory crucibles were considered as an alternative. Alumina was rejected, as uranium can reduce it with the formation of uranium-aluminium alloys. Magnesia and beryllia were available. The preliminary experiments established that calcium, 60 per cent in excess of the stoichiometric amount, was desirable for complete reduction.

Batches of 17·01g uranium dioxide were mixed with 8·07g calcium and pressed in a die. The load was critical, as too high a pressure caused the compact to flake on extrusion. A thin layer of prefired lime tamped into the bottom of the crucible ensured good charge separation and about 1g of -20 $+60$ mesh BSS calcium was pressed at the bottom of the charge. This calcium eliminated any tendency for the lime to cause incomplete reduction, and prevented fine particles of uranium dioxide from falling from the compact on ejection. The compact was ejected into the crucible which was placed in the bomb and covered with a graphite disc. The bomb was sealed, evacuated and purged with argon, and raised to 1200°C for 30 minutes before cooling. When cool, the crucible was removed from the bomb and the cake was quite readily pried loose. It was greyer and of a denser structure than the green cellular cakes produced in the large scale uncompacted reactions. The magnesia crucibles first used were cracked by the thermal shock of the reaction, in which the temperature rise was of the order of 500°C per second. Beryllia crucibles showed much greater resistance and were used for all subsequent reductions.

The cake was too small for economical jaw crushing, and owing to its high calcium content was too hard for hand crushing. It was crushed under a press in a mild steel pot until practically all the cake was below 10 mesh. A 500 ml *Pyrex* conical flask was used for leaching trials, but decantation was most inefficient. A glass 'pip' about 4 cm long and 1 cm diameter was therefore fused to one side of the base to contain the leached powder whilst the liquid was syphoned off. In this way all but about 2 ml of liquid could be removed without disturbing the powder. To prevent overheating, ice was added to the flask as required. Acid was added from a plunger pipette, and the flask was agitated by hand. As was expected, pH control with nitric acid only was difficult, and some uranium was lost by solution. When acetic acid only was used the high concentration of acetate ions caused a 'scum' of uranium particles to form which refused to settle and was not dispersed by wetting agents. Both disadvantages were eliminated by adding acetic acid equivalent to about 5 per cent of the acid requirements before continuing with nitric acid. The acetate ions buffered the solution at pH 5·5 provided that the molar ratio of free nitric acid to acetate was less than one. The pH was measured with indicator papers, since glass electrode readings were invalidated by fine uranium powder, and BDH universal indicator added to the solution gradually decomposed. Much weaker nitric acid was used towards the end of leaching to allow closer pH control. Leaching was regarded as complete when the rate of calcium removal, as measured by the rate of neutralization of nitric acid, was less than 5 ppm/minute; this normally took about three hours. The powder was settled for 10-15 minutes and collected in the pip. The liquid was syphoned off, and the powder washed with 1·5 N nitric acid, and several times with distilled water containing a wetting agent. It was transferred to a test-tube and dried by evacuation through a drying tower. The dry powder contained paper fibres, brush hairs and occasionally traces

EN EMPLOYANT la réduction au calcium, on peut obtenir de l'uranium non-pyrophorique de très grande pureté en forme de poudre avec des particules presque sphériques, le coefficient d'extraction étant très grand. Ce processus n'est pas neuf, mais il a été perfectionné à Harwell, où cette méthode est maintenant employée couramment. On peut préparer maintenant de l'uranium enrichi, et du U-235 ou U-233, en lots de 20 à 350 g. Puisque l'activité alpha de purs isotopes d'uranium est très grande, le processus doit être conduit dans une boîte à gants.

WENN MAN das Kalziumreduzierverfahren anwendet, kann man nichtpyrophorisches hochreines Uranpulver mit annähernd kugeligen Teilchen herstellen, wobei die Extraktionsausbeute gross ist. Der Prozess ist zwar nicht neu, doch ist er in Harwell verbessert worden, woselbst er jetzt ständig gebraucht wird. Man kann heute angereichertes Uran, oder reines U-235 oder U-233, in Mengen von 20–350 g herstellen. Da die Alpha-Aktivität reiner Uranisotope sehr hoch ist, muss der Prozess in einem Handschuhkasten ausgeführt werden.

EL MÉTODO de reducción por calcio puede producir polvo de uranio no pirofórico, de partículas aproximadamente esféricas y de gran pureza, a altas eficiencias de extracción. El procedimiento no es nuevo, pero ha sido mejorado merced a los trabajos realizados en Harwell, donde el método es ahora considerado como cuestión de rutina. Lotes de uranio enriquecido, y de U-235 y 233 puros pueden prepararse ahora en tamaños que varían entre 20g y 350g. La actividad alfa de los isótopos de uranio puro es muy elevada y los procesos tienen que llevarse a cabo dentro de un compartimiento con manguitos y guantes.

ПРИМЕНЯЯ МЕТОД восстановления кальцием, можно получить не пирофорический уран высокой степени чистоты в виде порошка, состоящего из почти сферических частиц, причем коэффициент извлечения очень большой. Этот процесс не нов, но он усовершенствован в Харвелле, где теперь является частью установленной практики. Существует теперь возможность приготавливать обогащенный уран, а также U-235 и U-233, в порциях от 20 до 350 г. В виду того что альфа-активность чистых изотопов урана очень велика, приходится вести эти процессы в защитной камере с перчатками.

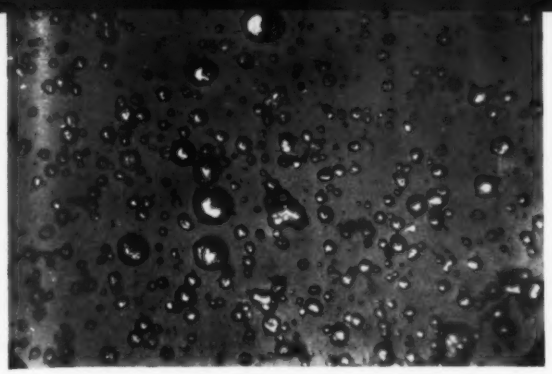


Fig 2 Photomicrograph shows spherical nature of particles. Sizes are around 10 microns

of beryllia, which together with a few larger uranium particles were removed by sieving.

Ten such runs were carried out. It was found that the acetate buffered nitric acid dissolved a negligible quantity of uranium, and faster settling uranium powder was obtained from the beryllia crucibles, with a consequently improved recovery. However, the main factor in efficient recovery was handling experience, and the yield rose from 90 per cent in the early experiments to more than 97 per cent for the last. Microscopic examination showed the powder consisted chiefly of near spheres of about 10μ particle size; the high bulk density of 11·7g cm^{-3} confirmed its spherical nature. A photomicrograph is given in Fig 2.

Over 99 per cent of the later powders produced passed a 200 mesh BSS sieve and a true density of 18·72g cm^{-3} was determined for the last. (Theoretical uranium density =19·05g cm^{-3}). This was estimated to correspond to an oxygen content of 0·1—0·3 per cent. Chemical analysis showed the presence of silicon and boron. This was suspected to derive from the glass leaching vessel, which for long periods was above pH 10. With the exception of this contamination the results were considered satisfactory and glove box work was begun.

The 15g scale production of U-233 powder

The gamma activity of U-233 is low, and protection is required only against its non-penetrating alpha activity. This is achieved by carrying out all operations in a sealed glove box maintained at slightly below atmospheric pressure so that any leakage is into the box, and no active material is carried into the surrounding air. A Perspex-panelled glove box of this type was used (Fig 3) in which the 'dry' (reduction) and 'wet' (leaching) sides were separated by a Perspex screen. All the equipment and materials necessary for the process were placed in the box, which was then sealed before starting work. Services such as argon supplies, vacuum lines, etc., were connected to the box. Two runs were carried out with natural uranium to test the installation. The box and apparatus were then thoroughly cleaned prior to handling U-233. This isotope was prepared in an identical manner to the later natural uranium runs, with the exception of a modification to the leaching procedure intended to reduce the silicon and boron contamination. The crushed cake was added to the water-ice mixture over about 30 minutes, after which the solution was kept acid during the whole leaching period with nitric acid alone. This reduced alkaline attack on the glass to a very short period, but the loss of uranium by solution in the nitric acid was increased and yields were reduced to the order of 92 per cent. The batches of powder obtained were silver grey in colour, indicating freedom from surface oxidation. The absence of unreduced oxide was deduced from the appearance of the reaction cakes. The powders settled rapidly during leaching, and very little was retained on a 100 mesh BSS sieve, suggesting a predominantly spherical particle shape. The powders were stored in sealed, evacuated tubes until required.

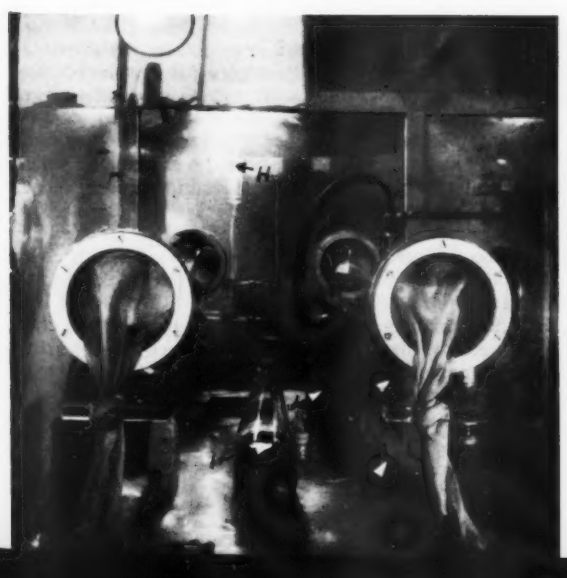
Development of technique on a 200g and 350g scale

The 15g scale work provided a great deal of data for the larger scale production of the uranium isotopes. A number of experimental reductions were carried out on a 200g scale and with the combined data the 350g scale experimental work required was little more than a test of the glove box facilities. The 15g scale work suggested the following modifications:

1. The largest convenient scale of operation to reduce contamination and uranium losses.
2. Replacement of the ceramic crucible by a refractory metal to lessen the risk of contamination and to make for robustness on handling.
3. Replacement of the glass leaching vessel by stainless steel to reduce boron and silicon contamination.
4. Assuming the preceding modification to be adopted, the use of buffered nitric acid for leaching to avoid solution losses of uranium.

The 200g scale charge was prepared much as on the smaller scale, using a larger die. The first reductions were carried out in tamped lime linings as no beryllia or magnesia crucibles of sufficient size were available. Later, metal crucibles were used. The graphite crucible cover

Fip 3 Glove boxes used for preparing U-233 on 15 gram scale. 'Wet' box on the left: 'Dry' on the right. A—expansion balloon, B—reaction vessel, C—furnace, D—press, E—compacting die on turntable, F and G—crusher, H—acid pipette, I—leaching tank, J—siphon bottle, K—drying tower in vacuum line, L—sieve, M—vacuum flask of ice



used on the 15g scale was suspected of causing contamination, and was replaced by a series of metal baffles which acted as a lid for the crucible and as radiation shields, (Fig 4). The bomb was sealed and argon-purged according to standard practice. The metal crucible worked very satisfactorily. Heating schedule investigations on this scale established two points. If the charge was cooled very soon after the reaction took place the uranium powder was spherical but very fine, and as a result leaching losses were high and the powder tended to become oxidized. Holding at 1150-1200°C increased the size of the uranium spheres, but cooling the charge slowly from the soaking temperature produced irregular particles, which were undesirable for hot compacting. The reaction cakes produced on the 200g scale were extremely hard and tough; they were crushed by hand, but the process was too laborious for dry box operation. A scaled down version of the original stainless steel 'tumbling barrel' with cooling coil (Fig 5),

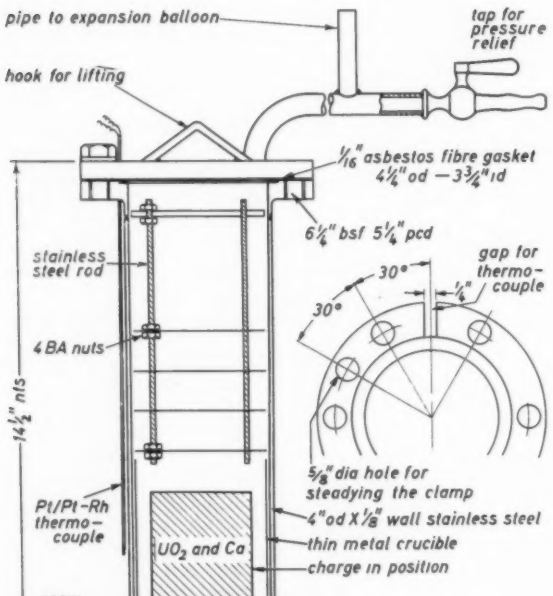


Fig 4 The reduction bomb assembled

was adopted for leaching, and gave satisfactory service. Only nitric acid was used in leaching, and the powder was washed with 1·5 N nitric acid and distilled water. When prepared by the preferred heating schedule more than 90 per cent of the uranium powder consisted of spheres of moderate size; the density was acceptable but rather low, about 18·5g cm^{-3}.

The dry box equipment described below was used (with the exception of the jaw crusher) for the production of two 350g scale natural uranium runs. The charge was compacted in a large die, and particular precautions were taken against segregation during loading. Since as little as 30 per cent excess calcium had been found adequate for complete reduction on a larger scale, it was believed that less than 60 per cent excess could with advantage be used on the 350g scale—e.g. a higher reaction temperature would be achieved. In the first such reduction, therefore, the calcium excess was 34 per cent (400g UO_2 : 160g Ca). The reduction procedure was standard. The cake was more easily

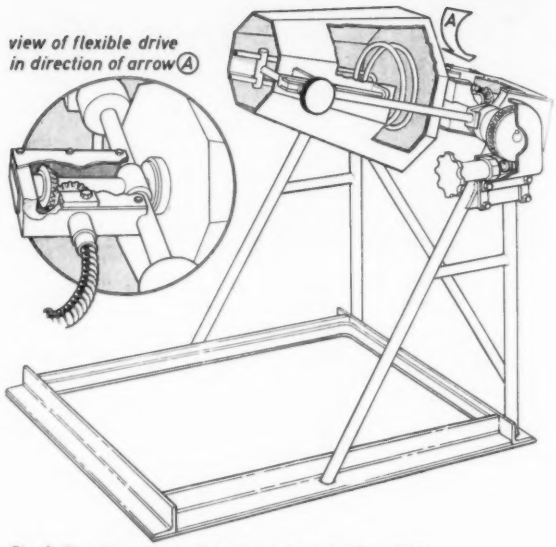


Fig 5 The leaching tank incorporates cooling coils

crushed than those of higher calcium content, and was darker in colour, but reduction was complete. It was leached in buffered nitric acid at a maximum temperature of only 21°C to decide whether leaching could be completed in a practical time at this low temperature, which would reduce oxidation of the uranium and solution losses to the nitric acid. The uranium powder obtained had pour, tap and true densities of 8·9, 10·5 and 18·73g cm^{-3} respectively, and it was concluded that adequate leaching was possible at 21°C. However, micro-examination showed it to consist of about 70 per cent spheres and 30 per cent irregular particles. These irregular particles were ascribed to the low calcium excess.

In the second natural uranium run the calcium excess was 50 per cent. The cake appeared satisfactory, and was completely reduced. The uranium powder produced consisted of about 95 per cent spheres and about 5 per cent irregular particles, and when hot compacted produced metal of density 18·64g cm^{-3}. It was concluded that the technique was satisfactory in all respects.

The 350g scale production of alpha-active metal powder

Three Perspex and angle-iron glove boxes, Figs 6, 7, connected by permanent transfer tunnels were built to house the 350g scale equipment, which was too bulky for a single box. The boxes could be kept at 2 in. w.g. below ambient pressure with either an air or an argon atmosphere. Argon was used during most of the active work. Three electric motors in the boxes were given separate atmospheres of nitrogen since commutator motors do not function satisfactorily in pure argon. All electrical controls from the boxes were brought out to a standard panel alongside. The furnace box was itself divided into two portions; the lower contained the vacuum trolley, from which unions were brought into the upper half, which contained the platinum/rhodium wound furnace and the cooler. The furnace was water jacketed to protect the Perspex walls. A crane was installed to transfer the bomb from the furnace to a water-jacketed cooler which chilled it rapidly. The crane carried radiation shields allowing the transfer to be carried out at about 1000°C. A jig for loading and unloading the bomb was also served by the crane.

The centre box housed the balances and press, and the transfer port through which the materials could be put into or removed from the entire box assembly. In glove

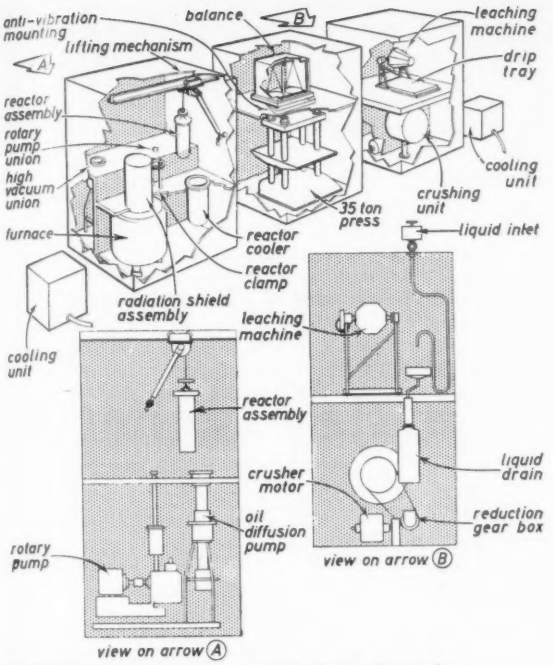


Fig 6 Schematic shows arrangement of glove boxes for production of powder on 350 gram scale

box work, physical effort must be kept to a minimum as the operator works at a mechanical disadvantage, and the press was installed with this in mind. The bottom platen was extended to cover almost the whole area of the box, and the heavy dies could be slid about without being lifted from one level to another. A steel cradle allowed the dies to be inverted without effort for ejection or emptying. The leaching box was divided into three compartments housing respectively the leaching tank, the working face of the jaw crusher, and the jaw crusher and leacher motors. The leaching tank cooling coil was supplied with refrigerated water from an external unit. Means for transferring liquids (e.g. the leaching acids) in and out of this box were provided. The jaw crusher was a specially designed small unit in stainless steel.

The equipment in these glove boxes was used for preparing batches of enriched uranium, U-235, and U-233 varying in size from 20g to 350g. Uranium powders were obtained at an overall process efficiency of 97-98 per cent. They were fabricated into shapes of high quality surface finish and of densities up to 98 per cent. of the theoretical value. Metal efficiencies in fabrication were over 99 per cent.

Considerable experience has been gained with the calcium reduction route as applied to glove box practice, and the production of the various uranium isotopes is now regarded as a routine process.

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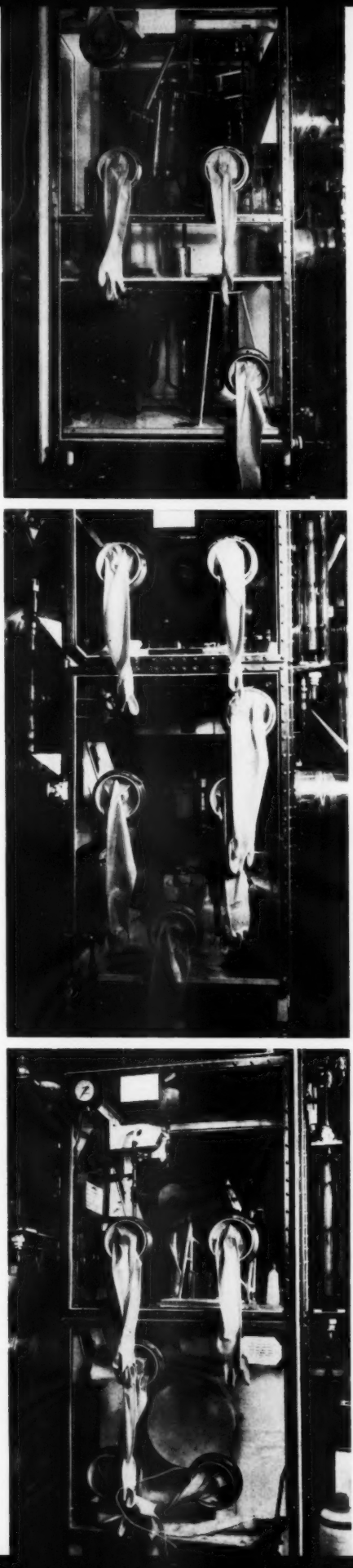


Fig 7 The actual glove boxes of fig 6. Above—furnace box; centre—press box; bottom—leaching box

Some 200 firms will take part in this exhibition, the first of its kind, which opens at Olympia this month. A number of the exhibits most likely to interest our readers are described in this preview.

NUCLEAR POWER will be at stand 102A and we shall be glad to see readers there at any time during the exhibition.

Instruments, Electronics and Automation Exhibition

Olympia May 7-17

Open daily, including Saturday, from 10 a.m. to 6 p.m., and until 9 p.m. on Friday 10 and Wednesday 15. Tickets will be available at the door.

A conference will be held concurrently with the exhibition, each day devoted to a special subject. The NUCLEAR DAY will be Thursday, May 9, and the programme is as follows:

11 a.m. *Chairman: D. D. Walker (BEAMA)*
Nuclear Power *by Sir Claude Gibb, chairman and managing director, Nuclear Power Plant Co Ltd*

3 p.m. Controlling a research reactor *by R. J. Cox, Electronics Division, UKAEA*
The place of analogue computers in reactor control *by J. Walker, Reactor Division, UKAEA*

3.45 p.m. Radioisotopes in the nucleonic industry *by H. Seligman, Head of Isotope Division, UKAEA*

AIRMEC LTD **STAND 408**

Radiation monitor (*type* 1021*B*). This may be used for detecting radioactive contamination of clothes, chemical glassware and other apparatus, for tracing radioactive materials in chemical analytical processes, and for the measurement of the contamination of any resulting effluent. Determination of radiation intensity from sources of unknown strength may be made with an accuracy of ± 2·5 per cent of full scale on ranges × 10 and × 100 and ± 10 per cent on ranges × 1 and ÷ 10. The instrument is normally fitted with a probe which is sensitive to beta particles and gamma rays, but a scintillation counter type of probe may also be supplied for the detection of alpha particles. A sliding shutter is provided in the beta-gamma probe to exclude beta particles and allow the probe to be made sensitive to gamma rays only. Visual indication is provided by a meter calibrated in counts per second, and audibly by loudspeaker. The output may be fed to a scaling unit, and the number of counts over a long period totalled.

ASSOCIATED AUTOMATION LTD **STAND 510**

Recording count controller. Developed for the AERE, Harwell, this provides a printed record of electrical pulses from a number of separate sources. Motor driven, it comprises six independent counter units each of which will receive pulses at the rate of 20 per second. Three of the units print up to 999 and one to 9999 pulses, whilst the remaining units repeat totals external to the recorder up to 99 and 999. Printing at a preselected count is accommodated by the inclusion of commutators directly coupled to the counter units. A pulse controlled mechanism governs line printing of the six counter units totals on 10 in. wide chart paper and operates the paper and carbon feeding device. An automatic counter zeroing device is operated from the same mechanism.

AUTOMATIC COIL WINDER AND ELECTRICAL EQUIPMENT CO LTD **STAND 942a**

A comprehensive range of electrical, electronic and nucleonic test gear will be shown, including items from the well-known *Avo* range and *Radiac* survey instruments. The *Avo* d.c. amplifier has been designed in conjunction with the AERE and the NPL to form a standardized piece of equipment.

BAIRD & TATLOCK LTD **STAND 515**

Many new and redesigned instruments will be exhibited, including the latest development in the *Analmatic* range of automatic instruments and laboratories. Of particular interest in this range is Mk II of the uranium analyser.

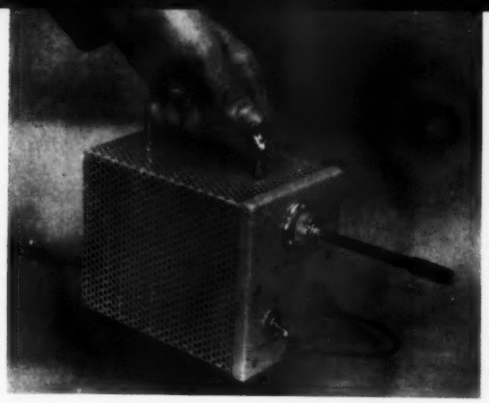
BALDWIN INSTRUMENT CO LTD **STAND 933**

Dosemeters. Three instruments will be shown suitable for gamma and X-radiation only, and one for all types of radiation over a wide range. Also exhibited will be the nucleonic level indicator (see NP, March p 98) and instruments in the *Atomat* range.

BRITISH FEDERAL WELDER & MACHINE CO LTD STAND 931
This exhibit will illustrate in particular the modern trend towards simplified and improved types of electronic controls for automatic resistance welding equipment. Instruments will include weld timers, synchronous controls, heat control units and autofeed equipment.

BRITISH THOMSON-HOUSTON CO LTD STAND 309
Leak-detectors. Three types of portable halogen leak-detectors will be shown for the location of leaks in pressure or vacuum systems or the detection of small concentrations of the halogens in other gases. They are not quantitative indicators but can detect a leakage rate as low as 1/50th of an ounce per year. In the testing of appliances not already containing a halogen-bearing compound, carbon tetrachloride is injected into the system as a tracer. Type HM (illustrated) weighs only 6¼ lb.

Other exhibits will be a portable vibration measuring equipment, a transistorized frequency meter and an optical tachometer.

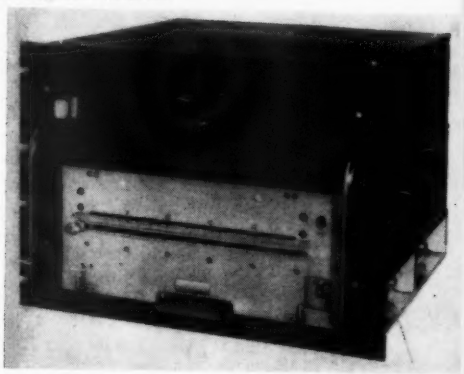


BTH—portable leak detector

CAMBRIDGE INSTRUMENT CO LTD STAND 601
A wide range of the latest measuring instruments will be shown for use in industry and science, comprising equipment for indication, recording and control by electrical, hydraulic and pneumatic methods.

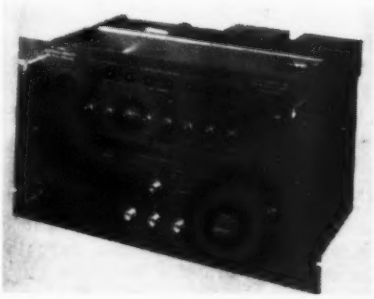
Amongst the many automatic controllers shown will be the new *electronic recorder-controllers,* which may be used in connexion with almost all classes of industrial and scientific applications.

ASSOCIATED AUTOMATION—recording count controller



A. E. CAWKELL STAND 716
Time calibrator (type PE31CU Mk 3). The instrument generates time markers in the range 0·5 to 1000 microsec which may be free running, gated from an external or internal gate having a continuously variable repetition rate of 1 microsec to 10 millisec, and a continuously variable length of 2 microsec to 100 millisec. A crystal controlled checker is fitted. The markers are available individually from sockets controlled by switches, or combined to give a timing comb type of presentation, variable in height, and either positive or negative going.

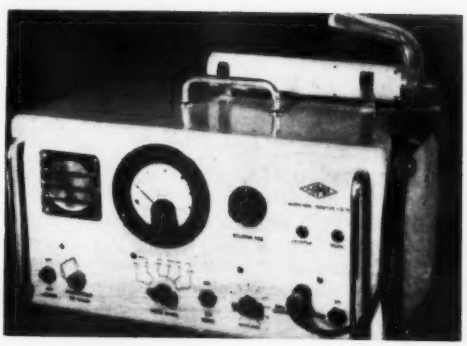
CAWKELL—time calibrator



CINEMA-TELEVISION LTD STAND 913
Precision interval timer. This new instrument has been developed for accurate measurement of intervals in the range 10 microsec to 10 sec in steps of 10 microsec with an accuracy of ± 0·002 per cent. A 100 kc/s crystal maintained oscillator is fed via an electronic gate into six cascaded decades, each associated with a panel mounted meter calibrated from 0 to 9.

Tolerance resistance bridge. This new addition to the *Cintel* range of bridges permits accurate measurement of resistors in the range 0·1 ohm to 100 megohms and may also be used to determine automatically the tolerance value of a resistor.

AIRMEC—radiation monitor



COSTAIN-JOHN BROWN STAND 607
The main feature will be glass-reinforced plastic caravan fitted out as a mobile test shop for use on sites for testing and calibrating control instruments before commissioning. The test equipment to be demonstrated will include: temperature recorder controller, differential pressure transmitter, thermostatically-controlled water bath, 100 in. mercury flow recorder, and displacement float type level controller.

It is hoped to illustrate the main instrumentation panel supplied for Dounreay.

CROMPTON PARKINSON LTD **STAND 408**

The display will include a comprehensive selection of electrical measuring instruments, an overload device for electrically driven plant and an electronic speed controller for d.c. variable speed fractional h.p. motors.

CROSBY VALVE & ENGINEERING CO LTD **STAND 912**

Level Controllers. Among the exhibits will be a Mason Neilan displacement type level controller shown automatically controlling the water level in a glass tank by adjusting the rate of discharge from a pump through a control valve. It will simultaneously transmit the actual water level to a remote receiving gauge. A fully sectioned instrument will be on show displaying the rugged design features.

DOWTY GROUP **STAND 108**

The Dowty Group will be represented by electrical and electronic products of Dowty Nucleonics Ltd. These will include the *dekatron counter* (*model* 5*D*20) used for high speed pulse counting in industrial and laboratory applications. Small and compact, this can be locally or remote controlled.

High speed counting equipment to be displayed embraces all components for complete installation, including a photo-transistor detector and lampheads conveniently small for siting in limited space.

DYNATRON RADIO LTD **STAND 550**

Transistor scaling unit (*type* 1287*A*). This is a compact and completely portable five-decade scaler designed for arduous use in the field. Particularly suitable for use in the detection and measurement of radioactivity in geological surveys and mining, it also has many other field applications.

Scanning pulse amplitude analyser (*type N*102). The instrument will accept pulses in the range 5V to 110V and transmits pulses within selected levels. The pulses are fed either to a scaling unit or ratemeter, the output of which may be fed into a chart recorder to give a continuous spectrum analysis. This is a new instrument with application in the nuclear field.

EKCO ELECTRONICS LTD **STAND 505**

Nucleonic equipment. Nucleonic counting equipment to be displayed or demonstrated will include a range of scalers, ratemeters, scintillation counters, radiation monitors and survey meters. There will also be a selection of ancillary equipment for the nucleonic laboratory, including linear amplifiers, a vibrating reed electrometer, power supply units, crystals for scintillation counting, geiger tubes and associated holders, instrument cases, lead castles, shielding and isotope containers.

A new beta scintillation counter will be shown working in conjunction with a five-decade scaler. Particularly useful for the assay of carbon 14 and tritium, it will provide overall counting efficiencies of 60 per cent and more with carbon 14 at room temperatures, and 20 per cent with tritium at — 20° C.

A complete counting equipment for the assay of very low activity gamma sources will also be shown.

The nucleonic gauge display unit will include a working demonstration of fully automatic control applied to the production of calendared material, and also a fluid density gamma gauge for use with pipe lines.

Reactor instrumentation, consisting of a typical control console and a reactor simulator, will be in operation.

ELCONTROL LTD **STAND 918**

Among a number of electronic control units on show will be an extension of the existing range of level controls for conductive liquids. A range of proximity switches have been produced suitable for use with free-flowing solids and non-conductive liquids.

ELECTRO METHODS LTD **STAND 904**

The display will include a wide range of rectangular miniature connectors with gold plated pins and sockets, set in melamine mouldings, and of high quality printed circuit connectors for 1/16 in. boards, also employing gold plated contacts and melamine mouldings.

ELECTRONIC INSTRUMENTS LTD **STAND 930**

The display will include a new *sonic gas analyser* for measuring concentrations of gases and binary mixtures. It has a wide range of applications and is used in atomic energy plants.

An addition to the *Vibron* series of instruments is the *electrometer* (*model* 33*C*). It is claimed to represent the practical limit of sensitivity, input resistance and zero stability for a direct reading electrometer. With appropriate accessories, it can be used for measuring currents of the order of 10^{-15} amp and resistance to 5×10^{15} ohms. Another accessory converts the electrometer into an accurate pH meter, giving 0·1 pH full scale deflexion over any part of the range and a zero stability of 0·001 pH.

Also in the *Vibron* series is a new megohmmeter, a high resistance bridge enabling high value resistors up to 100 million megohms to be measured to 1 per cent.

A working model of the EIL *industrial pH meter* will be shown recording the readings of six independent electrode systems through an automatic switching unit which selects each electrode in turn. The output is fed to an electro-pneumatic recorder and gives automatic process control.

ELLIOTT BROS (LONDON) LTD **STAND 411**

Nuclear power station instrumentation. The main feature of this stand will be the application of an integrated instrumentation system to a Calder Hall type reactor. It will include a reactor control desk, incorporating a Type ND 181 analogue computer to simulate the reactor, with supervisory panels equipped for carbon dioxide flow, heat transfer, gas pressure and purity maintenance, multipoint temperature measurement in fuel elements, control rod position control and indication, steam temperature, pressure and flow measurement control, and complete turbo-alternator and power distribution instrumentation. The burst slug detection equipment will be a multi-point scanning potentiometer recorder, also provided with automatic alarm.

One of the latest production models of the general purpose analogue computer G-PAC will be shown simulating a typical closed-loop servo system. New non-linear computing units demonstrated will include an electronic delay unit, a logarithmic multiplier and an arbitrary function generator.

EMI ELECTRONICS LTD **STAND 404**

Industrial TV. A new TV camera channel Mark V will be shown consisting of a compact, robust camera unit and control unit, designed to give excellent picture quality with marked simplicity of operation and control. The RF output may be directly connected to the aerial terminals of one or more standard TV receivers without modification. A video output can be provided for use with special

monitors with cable runs up to 500 ft between camera and control unit, and up to 2,000 ft between control unit and monitor. The photo-conductive tube used in this equipment will be on display as a separate component. Other television exhibits will be a precision monitor and a studio monitor.

ENDECOTTS (FILTERS) LTD **STAND 950**

Rapid separation of particles will be demonstrated with transparent rimmed test sieves on an *Endrock* vibrator. A mixture of coloured material inserted in the top of a nest of sieves will be seen graded in approximately 30 seconds into six different sizes, each size of which is a distinctive colour.

ERICSSON TELEPHONES LTD **STAND 613**

Nuclear reactor model. This will consist of two adjacent six foot panel units, one of which will contain the reactor model and the other the reactor power and deviation amplifier (type 129) and its associated equipment. When the control rod is withdrawn, the reactor simulator gives an output representing reactor power. This is displayed on a logarithmic meter while the time differential is displayed on a meter calibrated in reactor doubling time. The output of the reactor simulator also feeds the power and deviation amplifier (type 129) which normally works in conjunction with an ionization chamber and measures thermal neutron flux. A reading of reactor power is given by the power and deviation amplifier on a linear scale meter, and of power deviation on a linear scale of $\pm$ 5 per cent of demanded power. The demanded power can be set to a pre-determined level.

Head amplifier (*type* 128). In operation, this unit, designed in conjunction with the AERE for use with LIDO, would be enclosed in a submersible stainless steel case. It is normally used in conjunction with fission chamber of BF_3 neutron detectors to measure reactor power from subcritical levels to an order of several watts. For exhibition purposes, the amplifier chassis has been removed from its case and is open to inspection. It consists of a wide-bank amplifier which comprises a ring of three having a feedback ratio of 20/1 and a voltage gain of 36.

Other equipment to be shown will include counters, radiation monitors, ratemeters and survey meters.

ETHER LTD **STAND 904**

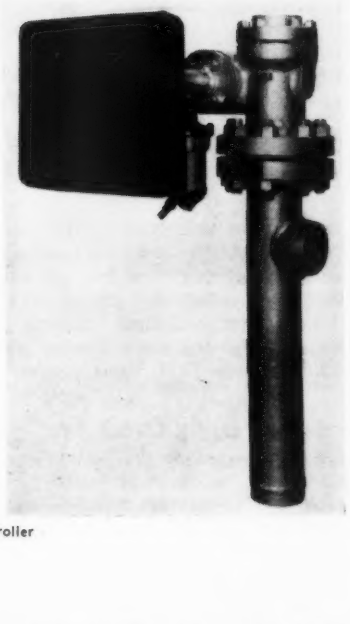
Transistrol temperature controller. This new, self-contained instrument is transistorized and operates over a wide range. It incorporates a conventional galvanometer as the measuring system and an indicating pointer which operates a photoelectric system, controlling the heating medium. The instrument is designed as a plug-in unit, suitable for wall or panel mounting.

EVERSHED AND VIGNOLES LTD **STAND 405**

Miniature recorder (*Mark* 2). Compact and versatile, the recorder weighs only 9 lb and is for incorporation into panels or control desks where space is limited, or for constant movement between check points. It is of the tapping type, the record being made by an ink impregnated ribbon brought into contact with the chart by the movement pointer.

Process controller (*Mark* 4). On show for the first time, this will be in the form of a special demonstration model to show the principles and method of operation. Completely electronic in nature, the controller employs no moving parts. The three control terms, proportional, integral and derivative, are generated separately, and are therefore free from interaction.

Also on show will be a new simple computer, a tank temperature unit, and a *Megger* low resistance testing set.



CROSBY VALVE—level controller

EVERSHED AND VIGNOLES—miniature recorder

ERICSSON—head amplifier

EKCO—nucleonic thickness gauge

FOSTER INSTRUMENT CO LTD **STAND 911**

Introscopes. A selection of these instruments will be shown for the internal inspection of hollow parts, tubes and internal surfaces which are not normally accessible. They are self-illuminated and give sharp close-up views. The smallest will enter a $\frac{1}{8}$ in. dia. hole to a depth of 4 in., and larger diameter jointed introscopes will be shown in a range of lengths to suit most applications in industry.

GENERAL ELECTRIC CO LTD **STAND 406**

On show will be a selection of instruments for the measurement of electrical quantities, representative types of electronic valves and cathode-ray tubes, semiconductor devices, barium titanate accelerometers and strain gauges, a 2kW high-frequency plastic preheater, a 4kVA spot welder and a 7kW high-frequency induction heater.

GENERAL RADIOLOGICAL LTD **STAND 703**

Reactor period meter. This equipment comprises two assemblies, the main unit and head amplifier. Two types are available covering current ranges 5×10^{-12} to 5×10^{-5} amp. Input current is displayed on a 5 in. panel meter with provision for operating a recorder from a 100mV output. Doubling times are displayed on a similar meter and remote recording is also provided. Doubling time ranges are 80 to infinity + 20 seconds and 20 to infinity + 5 seconds. Provision is made for the unit to operate in conjunction with warning and trip fault circuits, indication being given by a warning lamp. Time ranges for the two types are between 60 and 20 seconds positive and 15 and 5 seconds positive. The equipment operates on 50-60 c/s a.c. and 110-250V.

Fast neutron counter. Based on a design recommendation of the UKAEA, this new instrument by the GR subsidiary Solus Electron Tubes Ltd provides a means of measuring the biological hazard due to neutrons between the energy levels 0·1-15MeV with an accuracy of ± 20 per cent.

JAMES GORDON & CO LTD **STAND 510**

This exhibit is part of a joint display by Associated Automation Ltd. It will include pneumatic power operators for control of stop valves, automatic controls for boilers, control valves for steam, water, gas, etc.

HANOVIA LTD **STAND 917**

Detectolite. This portable, mains/battery fluorescent lamp is used in prospecting for uranium ore deposits. The discharge tube, made in a form of a spiral, is mounted in a light hand torch which also carries the filter and a small lighting bulb enabling the normal appearance of specimens to be examined under darkened conditions. The total weight of the unit is 16 lb and it is supplied with $5\frac{1}{2}$ ft of cable from control lamp to unit head, and $8\frac{1}{2}$ ft from control unit to mains.

Fluorescence lamp (model 16). This has been used in Australia to examine fluorescent treated residues from plants containing natural traces of uranium salts. In industry, it is used for flaw detection. It provides an intense UV beam at 3660 AU through heat-resistant filter.

HENDREY RELAYS LTD **STAND 218**

Among the control and laboratory apparatus to be displayed will be a newly developed spark recorder for instrumentation purposes in nuclear work, and geological survey equipment developed with and for AERE, Harwell.

There will also be a selection of relays, switches, and indicator and alarm units.

HONEYWELL-BROWN LTD **STAND 410**

ElectroniK instruments. Temperature, pressure, flow or any other variable which can be transduced to electrical terms can be measured, recorded, and controlled by *ElectroniK* continuous-balance instruments. On view will be several standard strip and circular chart potentiometer recorders and two special purpose models. These are the $\frac{1}{4}$ sec pen speed recorder and the *Duplex* recorder. The latter is a two-pen strip chart recorder which continuously records, on one chart, the measurement of two independent variables. Also in this range will be two precision indicators, vertical scale and multi-point.

A display of pneumatic transmitters, which can be used with miniature or conventional receivers, will include differential converter flow meters (high and low range), a differential converter liquid level controller, a pressure transmitter and an *ElectroniK* electro-pneumatic temperature transmitter.

INTEGRA, LEEDS & NORTHRUP LTD **STAND 301**

Twelve specimen models of the new *Speedomax Type H* covering electronically operated potentiometric indicators, round chart recorders, strip chart recorders and controllers will be shown. This new model is compact and range changing is quick and easy, external terminal boards and additional controls can be added quite simply.

Representative examples of the well known *Micromax* mechanically balanced recording potentiometer and the *Speedomax Type G* electronically operated high speed indicators and recorders will be included. A feature of the latter is the recently introduced X-Y recorder for plotting two functions; the X1-X2 recorder for plotting 2 X functions on the same coordinate of time, and the AZAR recorder which has adjustable zero, adjustable range, specially designed for laboratory and test use.

KELVIN & HUGHES (INDUSTRIAL) LTD **STAND 310**

The exhibit will include a new range of electronic controllers, and flowmeters, and *Autosonics*, the new system of automatic ultrasonic testing described in NP, April, p 162. New transistor type electronic controllers, employing a sensitive moving coil micro-ammeter in the measuring section and an indefinite life photo transistor in the control section, will also be shown.

GEORGE KENT LTD **STAND 403**

Electronic temperature recorder. This self-balancing recorder features all-mains operation with continuous standardizing, fast and continuous self-balancing by electronic amplifier and servo-motor, automatic cold-junction temperature compensation for themocouple measurements, and robust mechanical design of balancing system. It employs the null-balance principle of operation. The error signal is converted to mains frequency a.c. by a synchronous converter and amplified. The output is fed to the control winding of a servo-motor which drives the pen and rotates slidewire contacts until the error is zero. Scale ranges are from 2mV to 2V d.c. The recorder will be shown measuring the temperature of six different salts and metals heated by gas burners.

Another exhibit will be a synchronous converter, designed primarily for converting very small direct currents into alternating signals for easy drift-free amplification.

LABGEAR (CAMBRIDGE) LTD **STAND 501**

The theme of this exhibit will be the use of counting techniques as an aid to automation. The two fundamental instruments will be a new *recording ratemeter* (D.4124) and *printing counter* (D.4123). Both provide records of repetitive processes in traditional form.

An improved version of the automatic paper *chromato-*

gram scanning equipment will be demonstrated assaying radioactive paper chromatograms. An adaptation of this equipment to radioactive dust sampling will also be shown. In both cases the equipment will be shown in conjunction with a printing counter.

A new directional *scintillation counter* (D.4132) will be displayed with three interchangeable collimators giving end-window, wide angle and point source geometry. It will be demonstrated with a varying radioactive source which will provide a change of count rate on the recording ratemeter and will demonstrate the operation of the maximum/minimum limit triggers.

MARCONI INSTRUMENTS LTD **STAND 504**

Over thirty telecommunications test instruments, all of recent design, will be shown. Other exhibits will include instruments for pH and moisture measurement, and industrial X-ray apparatus. A section of the stand will be devoted to Marconi Industrial Television Equipment, and test apparatus for use with multichannel radio link equipment.

METROPOLITAN-VICKERS ELECTRICAL CO LTD STAND 408

Megistor phototransistor relay. This new instrument is intended for use instead of mechanical limit switches in cases where the initiator is inaccessible and where the speed of operation of a mechanical switch may lead to wear and failure. Total power consumption is only 16W and the relay has printed circuits. Typical applications are counting, level control, warning devices, height gauges etc.

Metrovick 950 *digital computer*. This is a general purpose machine, designed for use in solving a wide range of mathematical, engineering and scientific problems. It is simple and compact, overall dimensions being about 15 by 5 by 6 ft.

Mass spectrometer (*type MS6L*). Specifically designed as a simple, portable leak detector, it detects and measures very small concentrations of one gas in another with high sensitivity—1 part in 200,000 for helium in air. It can be used for testing pressurized or evacuated systems and will test for and locate leaks and measure leakage rates. Minimum detectable leak in a vacuum system is of the order 5×10^{-7} msec.

MINERVA DETECTOR CO LTD **STAND 930**

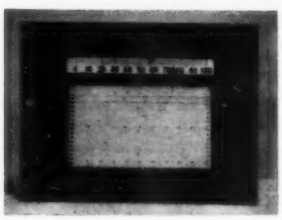
Nuclear fire detector. This consists of a cold cathode, gas-filled tube on a moulded base, attached to two ionization chambers, one of which is open to the air. The gas is ionized by alpha emission from a long-lived radium compound giving a current of the order of 10 amp. If a trace of smoke enters the open chamber the ionization current is reduced, increasing the effective impedance of that part of the circuit, thus raising the potential of the trigger electrode of the cathode tube and causing it to trigger. It passes a current of 10mA which operates the relay controlling the alarm bells and signal lamps. One detector protects about 1,000 ft² of floor area.

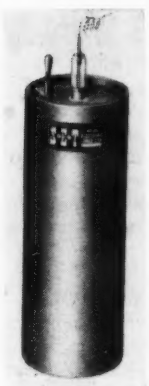
MORGAN CRUCIBLE CO LTD **STAND 927**

Megistor resistor. This high value resistor, manufactured to AERE specification, is particularly suitable for use in the small current circuits of radiation detection and monitoring equipment. It is sealed into an evacuated glass envelope giving a high degree of stability, and the outside of the envelope is coated with a water-repellent silicone lacquer. The resistance range is 10^7 to 10^{14} ohms, the normal selection tolerance being $\pm$ 10 per cent. Maximum overall dimensions of the envelope are $1\frac{7}{8}$ in. long by 7/32 in. dia. The resistors are suitable for a normal working in the range 0 to 300 V and 0 to 60° C.

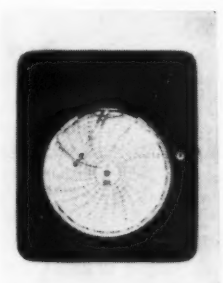
HANOVIA—' Detectolite '

HONEY-BROWN—' Duplex ' recorder





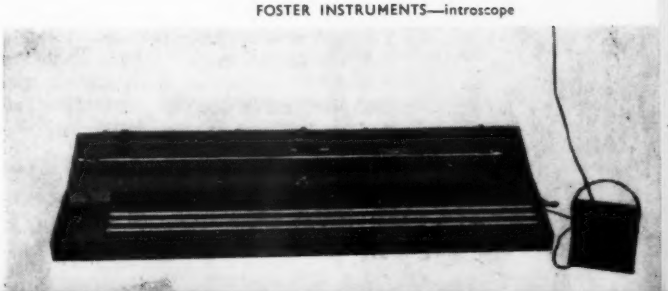
SOLUS ELECTRON TUBES—fast neutron counter



KENT—electronic temperature recorder

MORGAN CRUCIBLE—Megistor resistors

FOSTER INSTRUMENTS—introscope



NASH AND THOMPSON LTD **STAND 105**

A range of plastic and liquid scintillators will be exhibited. A new material, known as *Naton*—11, consists of a combination of organic phosphors held in solid solution in polyvinyl toluene. It has a pulse height of 60 per cent of a commercially available anthracene crystal of the same dimensions. Decay time is of the order of $2 - 3 \times 10^{9}$ and density 1·05 g/cc. The *N*—11 *X-ray scintillator* to be shown is a more sensitive development of the air equivalent scintillator. The present standard liquid scintillator is a solution of p-terphenyl in toluene with a small quantity of Popop added as secondary solute. It is available in bottles or sealed in glass containers ready for use.

A selection of scintillation purity chemicals for research, including materials such as anthracene and stilbene for crystal growing, are also available.

NEGRETTI & ZAMBRA LTD **STAND 503**

Transformer temperature controller. This prevents damage to an electrical power transformer, due to overheating as a result of overloading, by starting up a cooling fan or pump circulating oil. It provides visual or audible warning when dangerous or critical conditions are approached and operates trip mechanism in the power line to isolate the transformer in the event of an extreme or dangerous load. Any model can be fitted with a remote transmission system. The instrument to be shown is of the flush panel mounted type, and is used in conjunction with a heater bulb which reflects the temperature of the actual winding and therefore gives a very quick response to increases in temperature caused by sudden increase in load.

PHILIPS ELECTRICAL LTD **STAND 910**

Hand and clothing monitor. Developed to UKAEA design, main function of this well-known equipment is to check workers' hands for beta-gamma contamination, and clothing for alpha and beta-gamma contamination. The two hand units at waist height employ horizontally mounted thin-walled geiger tubes. Below this, connected to their respective circuits by flexible cables, are the frisking probes, one containing a geiger counter for beta-gamma measurement and the other a thin-walled scintillation counter for alpha detection. The unit also houses the HT and EHT power supplies, timing and counting circuits, meters, indicator lights, etc. As the monitor itself may become contaminated, it is designed to ensure ease of cleaning and replacement of contaminated parts.

PULLIN GROUP **STAND 925**

Portable multi-range test sets and panel mounting instruments with a contour styled Perspex dial cover fitted to certain ranges of instruments will be shown by Measuring Instruments (Pullin) Ltd. The styling greatly enhances the appearance of these instruments and gives greater clarity and legibility.

PYE & CO LTD, W. G. **STAND 501**

Master pH meter. Used at Calder Hall, this direct reading, mains operated instrument is a development of the *Universal* model. It incorporates several new features: effective scale of 0-14 pH is 11 in. long, giving good discrimination; a scale overlap of 6 pH units allows wide pH range titrations to be made without changing the range switch; and full automatic temperature compensation means that the instrument can be buffered at one temperature and readings made at any other.

RACAL ENGINEERING LTD **STAND 932**

Digital pulse delay generator. This equipment is designed to generate precision delays between an input and output pulse in the range 3 microsecs to 1 sec with an accuracy of $\pm$ 1 microsec. Three versions are available giving delay times of 9,999, 99,999 and 999,999 microsecs in increments of 1 microsec. The required delay is set up by operation of ten-position switches, each associated with a decade.

Digital microsecond chronometer. Designed to measure the time interval between two events to an accuracy of $\pm$ 1 microsec, this instrument gives direct reading visual display, and the reading is held until the instrument is manually reset. It employs digital techniques throughout to reduce ambiguity of result. The range is 3 microsec to 1 sec.

ROTAMETER MANUFACTURING CO LTD **STAND 935**

Continuous weighing density meter. This meter, for liquids and slurries, will be demonstrated as a working model in which glass pipeline will be used with PTFE bellows connectors. This instrument consists essentially of a loop of pipe carrying the flowing fluid weighed continuously on a pneumatic force balance. Output range of 3-15 psig is linearly related to fluid density. Any liquid or slurry that can be piped may be metered, subject only to the limitations of the flexible connexions.

The *Ekstrom* liquid level indicator will also be shown working, the exhibit being fitted with the magnetic-coupled limit switches now available. Of simple design, this instrument is useful for handling corrosive, toxic or inflammable liquids.

W. H. SANDERS (ELECTRONICS) LTD **STAND 710**

Among the exhibits will be a range of encapsulated transductors and rack mounted magnetic amplifier chassis, for use in automatic control systems. Also on show will be a cabinet containing a number of various magnetic amplifier chassis as used in the automatic control of industrial processes.

SAVAGE & PARSONS LTD **STAND 302**

A selection of new remote handling equipment developed in collaboration with AERE, Harwell, will be shown, including the *Master Slave Manipulator* (see NP, April, p 144–5). The exhibit will also include a range of what are claimed to be the most accurate remote reading resistance thermometers available commercially. Battery operated, they have an overall accuracy of $\pm 1^{\circ}$ and a sensitivity of $\pm 0{\cdot}1\,^{\circ}C$. Six models are available to cover the range -50 to $+250\,^{\circ}C$.

SOUTHERN INSTRUMENTS (OSCILLOGRAPH DIVISION) **STAND 100**

Universal oscillograph. This is a new type of cathode-ray oscillograph developed to provide a multichannel recording equipment of great flexibility. The 3in. dia. recording tubes are separate from the main equipment, housed in a cabinet to which the camera and optical system are fitted. Power supplies and driving voltages are supplied to a master distribution panel in this unit by means of flexible cables. The amplifiers and their power supplies are housed in a separate console. Up to twelve channels, with a separate tube for time marking, can be accommodated.

STANDARD TELEPHONES AND CABLES LTD **STAND 307**

Stantec Zebra digital computer. This is a general purpose computer of medium size and speed, suitable for carrying out a large variety of information processing problems in research establishments, and in industrial and commercial

organizations. The version to be shown (including input and output equipment) is primarily a mathematical machine, with applications to mechanical, electrical, structural and aeronautical design and development work. The machine is also of great use in analytical work and in the compilation of mathematical and navigational tables.

SUNVIC CONTROLS LTD **STAND 506**

Pulse height analyser. This is a rack mounting instrument for the analysis of a complex pulse amplitude spectrum into groups or channels of a known height. It employs a magneto-strictive delay line storage system and the number of channels is either 70, capable of counting over 10^7 pulses, or 100, counting more than 16,000 pulses. Accuracy and stability are 1 in 1,000.

Single and multipoint high speed chart recorders will also be shown with examples of plug-in range bobbins, and also an instrument desk for a research reactor.

TAYLOR-SHORT & MASON LTD **STAND 605**

The display will include conventional type pneumatically operated *Fulscope* indicators, recorders and controllers for the measurement of flow, liquid level, temperature, pressure and humidity. It is hoped to show also a new potentiometer transmitter for giving thermocouple temperature coverage in pneumatic and/or electric output.

TOWNSON & MERCER LTD **STAND 614**

Thermostat bath. A high precision instrument, this bath has made possible the control of radioactivity by calorimetry. It gives sustained accuracy over long periods of ±0·001°C and can be operated up to 120°C with oil. The capacity of the bath is about 10 gallons.

Also on show will be remote handling tongs for operating through a lead ball in 2 to 4in. lead walls. They feature interchangeable head and jaws and three lengths of operating rod. Jaw grip is positive and spring-opened, and can be locked in position.

A selection of glove boxes will be exhibited, including a flexible cabinet constructed entirely of PVC sheet. Both the box and the separate air lock fasten with a special type of zip fastener. To keep its shape it is maintained at a very small positive pressure by feeding in an inert gas such as nitrogen, or sterile air. The gloves are also made of PVC sheet and are welded into position.

RONALD TRIST & CO LTD **STAND 802**

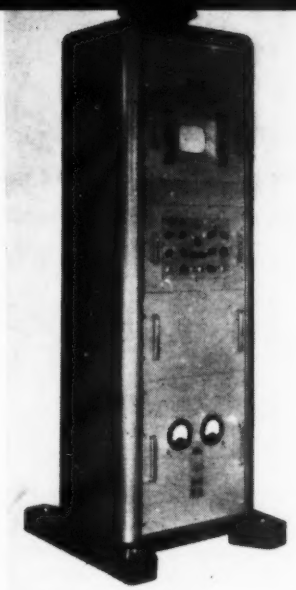
Level control equipment. A range of *Mobrey* magnetic level switches, constructed in various materials, may be seen. They are now available for working pressures up to 3,000 psi and working temperatures up to 750°F for use in almost any liquid. Switches will be shown operating in conjunction with alarm panels giving both visible and audible warning of high or low level.

20TH CENTURY ELECTRONICS LTD **STAND 946**

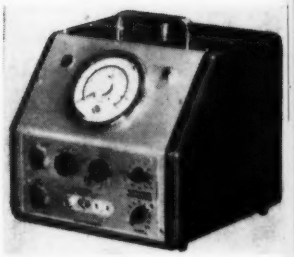
Counter tubes. A range of over fifty types of geiger counter covering a variety of applications may be seen. There will also be many types of counters for fast and slow neutrons, including fission counters designed for installation in the control systems of high power and fast reactors. This range includes counters of various sensitivities and characteristics.

A 2in. diameter photo-multiplier tube has been developed for scintillation counting and gamma spectroscopy. It incorporates a semi-transparent Sb—Cs cathode and improved dynode structure.

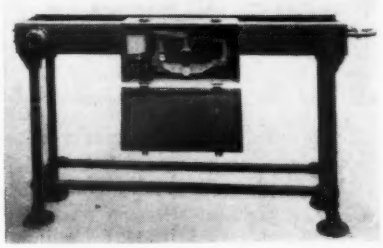
In addition, a range of precision electrostatically deflected instrument cathode ray tubes will be shown, and a new 5in. diameter tube with eight independent guns.



SUNVIC—pulse height analyser

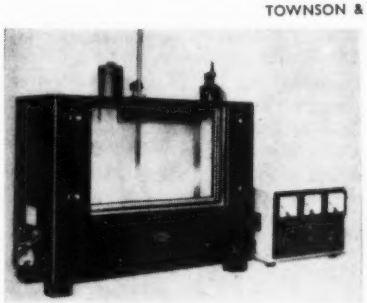


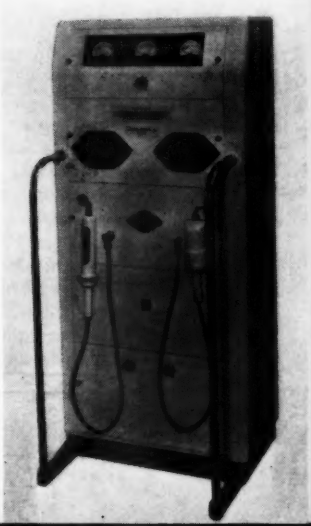
PYE—master pH meter



ROTAMETER—continuous weighing density meter

TOWNSON & MERCER—thermostat bath





PHILIPS—hand and clothing monitor

In considering gas-cooled reactor design, some method is needed for estimating the effect on heat transfer of changes in fin material and coolant. This article shows how this can be done

Some characteristics of reactor gas cooling systems

P. FORTESCUE PhD WhSc Deputy Chief Scientist, Reactor Division, AERE, Harwell

WITH GAS-COOLED reactor fuel cans using circumferential fins or grossly roughened surface, heat transfer work with a given fin material and coolant gas can be generalized by plotting Stanton number against Reynolds number multiplied by the ratio of the thermal conductivity of the gas to that of the metal. For this type of surface a figure of merit in terms of molecular weight and specific heat is obtained.

WHENEVER secondary surface (for instance, fins) is employed to assist in cooling, some part of the total temperature difference available for cooling will inevitably be used up by heat conduction within the fin material. Since heat transfer from the surfaces to the coolant is subject to different laws from those governing the simple conduction process which brings the heat up to the surface, the concept of fin efficiency is introduced to allow of the generalization of experimental results. This is defined as the ratio of the heat transferred from the body considered, to that which would have been transferred under identical external conditions, but with infinitely conductive fin material. For the simple case of uniform surface heat transfer coefficient and uniform gas temperature, there are available analytical expressions for fin efficiency. The form of these expressions depends on the geometrical shape of the fins, but in all cases efficiency is expressible as some function of the non-dimensional group $\frac{xh}{k_m}$, for any fixed fin shape, x being a characteristic linear dimension, h the surface heat transfer coefficient, and k_m the fin material thermal conductivity. In the case of interest to reactor designers—finned fuel elements in relatively large ducts—the surface heat transfer coefficient and gas temperature are not uniform. However, provided fluid temperature and velocity distributions are not seriously modified by changes in flow conditions (i.e. changes in R_e and P_r), fin efficiency will still be some function of $\frac{xh}{k_m}$ only, for a given fin shape.

Fin efficiency

We find experimentally that with circumferential fins, although (fin root) heat transfer coefficient, expressed in non-dimensional form as Stanton Number S_t, decreases with increasing Reynolds Number, the friction factor f remains constant. Remembering that a close relation exists between S_t and f, due to the similarity of the mechanisms of momentum and heat transfer, this suggests that it might be worth exploring the consequences of assuming that the observed fall in S_t with increasing Reynolds Number was solely due to fin efficiency variation (Fig 1).

The importance of this approach lies in the fact that, as will be shown, this assumption allows us to extend a set of results obtained with a given fin material and coolant to the case of varied fin conductivity and varied coolant gas properties with hardly any increase in complication of presentation. The justification for the assumption will of course rest in the extent to which experiment shows satisfactory correlation over the necessary range of these quantities.

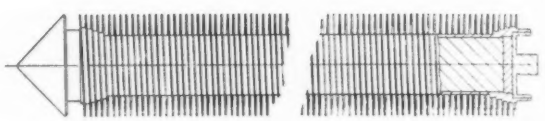


Fig 1 Cross section of Calder Hall fuel element shows typical deep helical finning

Let S_t' be the Stanton Number that would have been observed with infinitely conducting fins. We are saying that experimentaly S_t' is independent of R_e the Reynolds Number, for a given fluid, and to this statement we add the rule (well established for simple surfaces) that with varied fluid properties, S_t' would vary as $P_r^{\frac{2}{3}}$, where P_r is the Prandtl Number.

Thus, $S_t' = CP_r^{\frac{2}{3}}$ where $S_t' = \dfrac{h}{\rho V c_p}$

and $P_r = \dfrac{c_p \mu}{k_g}$

multiplying both sides by $R_e P_r$ gives

$$\frac{hd}{k_g} = C R_e P_r^{\frac{1}{3}}$$

or $$\frac{hd}{k_m} = C R_e P_r^{\frac{1}{3}} \frac{k_g}{k_m}$$

where d is a characteristic linear dimension and k_g the thermal conductivity of the gas. C is a constant.

For a given geometry of fins and duct, we may use d as the characteristic length x, governing the fin efficiency. Fin efficiency being a function of $\frac{hd}{k_m}$ is now seen to be a function of $R_e P_r^{\frac{1}{3}} \frac{k_g}{k_m}$.

Now S_t, the Stanton Number based on fin *root* temperatures with finite fin conductivity, is by definition equal to

$S_t' \times$ fin efficiency

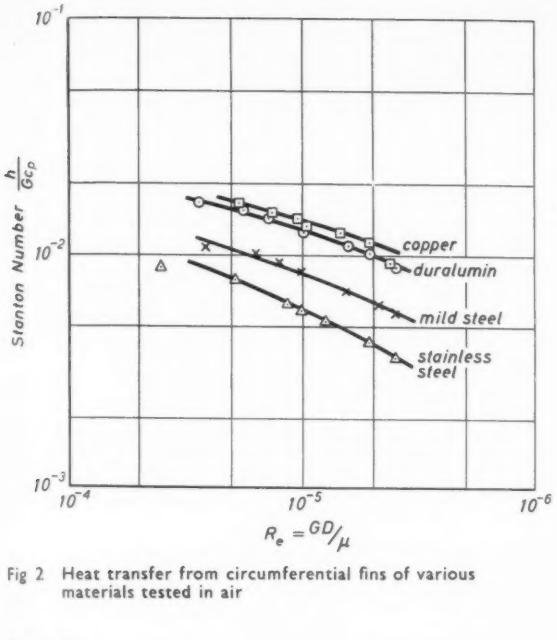


Fig 2 Heat transfer from circumferential fins of various materials tested in air

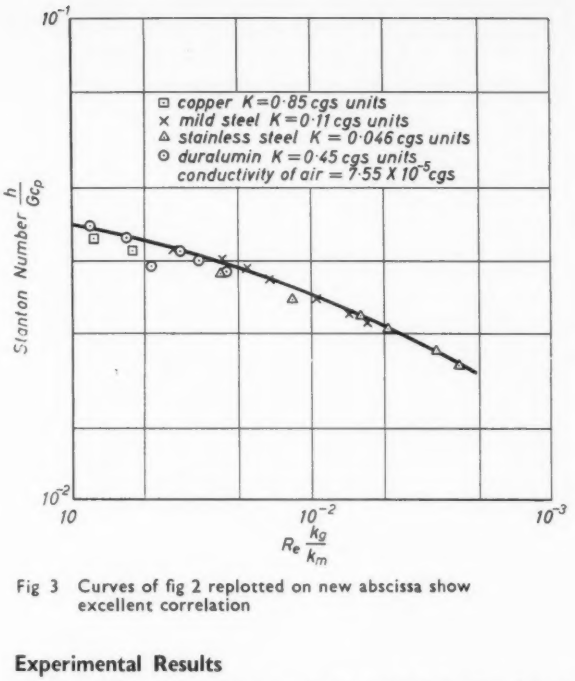


Fig 3 Curves of fig 2 replotted on new abscissa show excellent correlation

So we get

$$S_t P_r^{\frac{2}{3}} = \phi\left(R_e P_r^{\frac{1}{3}} \frac{k_g}{k_m}\right) \quad \ldots\ldots\ldots\ldots 1$$

Since P_r is very nearly a constant for all gases under all conditions, we can certainly neglect the $P_r^{\frac{1}{3}}$ within the function bracket above, particularly as the whole function (i.e. the fin efficiency) only governs a small part generally of the total temperature difference. For all real gases we can in fact neglect the Prandtl Number variation completely, and so arrive at the important conclusion that S_t should be a function solely of $R_e \frac{k_g}{k_m}$. This allows the presentation on a single curve of the heat transfer properties of finned bodies of varied conductivity cooled by all gases (Figs 2, 3, 4, 5).

Experimental Results

Figure 2 shows the direct result of tests of similar finned cartridges of conductivity varying from that of copper to that of stainless steel, which certainly covers more than any range likely to be of practical interest. Notice that different curves are required for each material, and there is of course no way of predicting from a test on one material what result another material would give, save by interpolation of a series of tests covering a range of conductivity. Figure 3 shows the same results plotted according to the present suggestion, that is S_t plotted against $R_e \frac{k_g}{k_m}$ from which it will be seen that all results fall reasonably close to a single curve.

Comparison of Figures 4 and 5, demonstrating the same

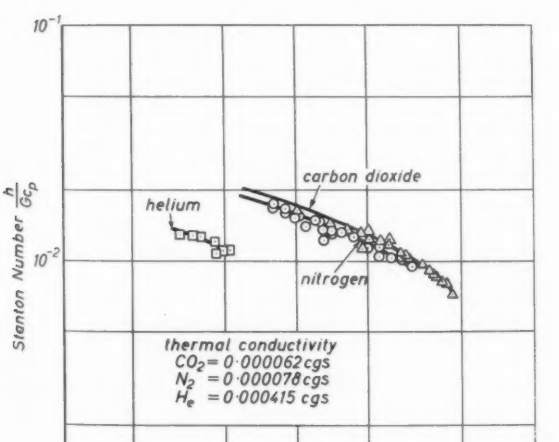


Fig 4 Heat transfer for the same fins in different gases

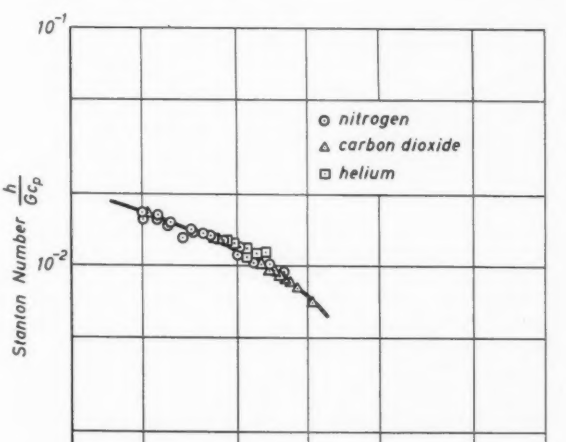


Fig 5 Points from fig 4 replotted lie on good curve

LORSQU'ON EMPLOIE des ailettes péralesriphé comme surface de la transmission secondaire de la chaleur dans les éléments du combustible de forme cylindrique (tels qu'ils sont employés dans les réacteurs anglais à refroidissement au gaz), on peut généraliser les résultats de l'étude conduite avec une matière d'ailettes et réfrigérant gazeux donnés, en présentant ces résultats au moyen de certains paramètres sans dimension. Le coefficient de qualité pour une ailette donnée est dérivé pour des gaz différents ; on montre que, pour les gaz ayant un grand coefficient de qualité, tels que l'hydrogène, les ailettes deviennent très courtes et fortes, et disparaissent à la fin.

WENN MAN UMFANGSRIPPEN als sekundare Wärmeübertragungsoberfläche der zylindrischen Brennstoffelemente (wie in britischen luftgekühlten Reaktoren angewandt) anwendet, kann die Experimentalarbeit mit dem gegebenen Rippenmaterial und Kühlgas dadurch verallgemeinert werden, dass man die Ergebnisse als dimensionslose Parameter darstellt. Der Gütefaktor einer gegebenen Rippenkonstruktion wird für verschiedene Gase abgeleitet ; man beweist, dass für Gase mit einem hohen Gütefaktor, wie z.B. Wasserstoff, die Rippen sehr kurz und stark werden, um schliesslich zu verschwinden.

CUANDO SE USAN aletas circunferenciales para superficie secundaria de transferencia de calor en elementos combustibles cilíndricos, del tipo usado en los reactores británicos enfriados por gas, el trabajo experimental con un determinado material para aletas y gas enfriador, puede generalizarse mediante la presentación de resultados en la forma de ciertos parámetros sin dimensión. Para un diseño determinado de aleta se deriva un factor de mérito para diferentes gases y se demuestra que para gases de mérito elevado, como el hidrógeno, las aletas se harán cortas y gruesas, y desaparecerán finalmente.

КОГДА ПЕРИФЕРИЙНЫЕ ребра применяются как поверхность вторичной теплопередачи в цилиндрических элементах топлива (типа, употребляемого в великобританских реакторах с воздушным охлаждением), существует возможность обобщения результатов исследования данного материала ребер и охлаждающего газа, если эти результаты представить в виде определенных безразмерных параметров. Коэффициент качества для данной конструкции ребра выводится для различных газов; оказывается, что в случае газов с высоким коэффициентом качества (как напр. водород) ребра сокращаются и толстеют и в конце концов исчезают.

effect, this time varying gas conductivity over a sevenfold range (helium to nitrogen), shows that this method of plotting covers this case too.

Thus with circumferential fins, heat transfer results obtained with a particular fin material, working in either air, or CO_2 may be used directly for any conductivity material in any gas, simply by using an *effective* Reynolds Number equal to the true one multiplied by $\frac{k_g}{k_m}$ these two coefficients being expressed as fractions of the test condition values.

Arising from this it follows that use of high conductivity gases as coolants will demand lower and thicker fins than at present if poor fin efficiencies are to be avoided. Furthermore, experimental heat transfer work for such systems will have to employ high conductivity gases also, because in air, for example, high Reynolds Numbers would have to be employed to cover the effective working range properly. Tests at the sort of Reynolds Number easily obtained in air (without excessive pressure or compressibility troubles) would not in fact be able to depress the efficiency of the sort of fins appropriate to, say, hydrogen cooling, to the point at which changes in, for instance, fin thickness significantly affect the result.

The gas merit figure

In the case of circumferential fins we have seen that we may put

$$S_t = \phi\left(R_e \frac{k_g}{k_m}\right)$$

Now,

$$R_e = \frac{Wd}{a_g \mu}$$

$$\frac{\mu}{k_g} = \frac{P_r}{c_p}$$

$$W = \frac{H}{c_p \Delta T} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

therefore,

$$S_t = \phi\left(\frac{Hd}{\Delta T a P_r k_m}\right)$$

Since P_r is virtually constant for all gases, this means that if we take a given core design operating at a given total heat release, we will get a constant value of S_t for all gases, provided the flow is adjusted in each case to give a fixed value of coolant temperature rise.

Now the maximum metal temperature in the core is related to the coolant temperature rise and S_t by Ginns' Equation, which may be expressed in this form

$$\frac{T_{max} - T_1}{\Delta T} = \tfrac{1}{2}\left\{1 + \frac{\sqrt{1 + \left(\frac{a\pi Q}{A\, S_t}\right)^2}}{\sin \frac{\pi}{2} Q}\right\} \quad \ldots\ldots 3$$

The point of importance is: for a given core and flux distribution, operation at constant ΔT and S_t implies that the maximum metal temperature is also fixed.

We thus come to the important conclusion that with circumferential fins, we have a very convenient basis of comparing the effectiveness of different coolants, for if the comparison is made at the same heat output and coolant temperature rise, it follows that the maximum metal

temperature is automatically also constant, no matter what the form of the fins, provided they are the same in the cases compared.

The relative merit of the coolants can now be expressed in terms of the relative pumping power required to establish the given coolant temperature rise. The expression is a simple function of the gas properties only, and makes no assumptions about heat transfer. Thus:

Pumping Power = Volume Flow × Pressure Drop.

$$h_p = Va \times \frac{2\rho V^2 fl}{d}$$

Putting $d = \frac{4al}{A}$ and $H = \rho Vac_p\Delta T$

gives $$h_p = \frac{fA}{2\rho^2 c_p{}^3}\left(\frac{H}{a\Delta T}\right)^3 \quad \ldots\ldots\ldots\ldots 4$$

Since this comes straight from the definition of friction without further assumptions about how this is related to heat transfer, it is true whether fins are used or not.

We have thus reached the conclusion that for a given power output per unit duct cross section, per degree of coolant temperature rise, the pumping power required by a given core design is proportional to $f/(\rho^2 c_p{}^3)$ or, at a given pressure, to $f/(M^2 c_p{}^3)$.

In general, this information is of no great help in assessing the relative merits of coolant gases, for not only do we need to know how f varies with the gas properties (expressed in the form of Reynolds Number), but the resulting maximum metal temperature is not necessarily constant in the comparison.

Wide, low cores

However, in the case of circumferential fins (of whatever shape), it so happens that f is independent of Reynolds Number, and (by reason of (3) and (2)), the maximum metal temperature is independent of the nature of the coolant when $H/\Delta Ta$ is constant. The criterion $M^2 c_p{}^3$ is in this case of real significance as it indicates the relative pumping power requirements of different gases under unusefully comparable conditions.

It is perhaps worth observing here in passing that what counts is the heat output per unit total coolant channel cross section, which points directly to the need, so far as cooling is concerned, for keeping the greatest possible flow area, one way of achieving which would be to use large diameter short cores. The point is mentioned to draw attention to the fact that the ultimate choice of duct size and reactor shape must be the result of a straight fight between nuclear and heat transfer considerations, and that so far as the latter are concerned, it always pays handsomely to keep up the total channel area by all means possible, provided that the requisite external duct connexion areas can be accommodated.

Returning to the question of comparison of coolants, we have seen that term $(M^2 c_p{}^3)$ is a convenient measure of the relative power expenditure required to produce the same cooling with different gases with the same fin design (Fig 6).

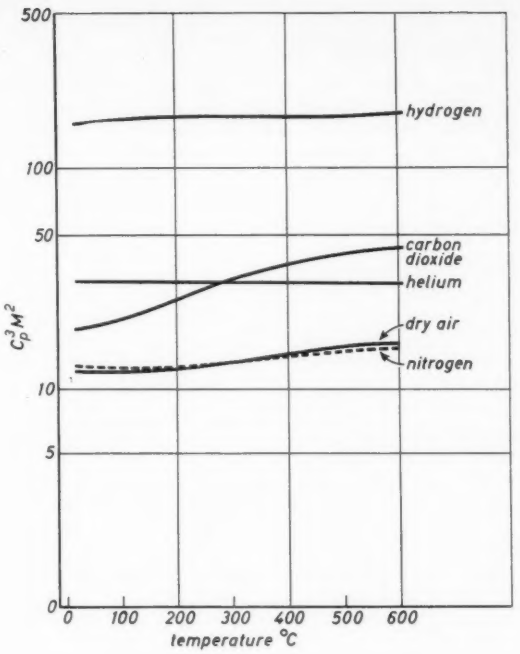


Fig 6 Figure of merit indicates relative power required to give same cooling with the same fin in different gases

Better gases, lower fins

Now, we may not wish to produce the same degree of cooling when we change our coolant. For instance, using hydrogen to give only the same cooling that could be got with CO_2 would be to waste the potentialities of the former gas by reducing pumping power to an unnecessarily low value. It would be much better to keep the same order of pumping power, and increase the heat output instead. The important point to note here is that even though core ratings rather than pumping power would in practice be adjusted to suit the coolant used, our criterion is still of value. The point is clarified if we imagine the design change as taking place in two steps—first, a change of coolant at the same rating, resulting in the change of pumping power requirement given by our criterion and no temperature changes—followed by an adjustment of flow to maintain either the maximum metal, or the outlet temperature at the required values at the new desired rating.

If the coolant temperature rise were the limitation to be maintained, the final pumping power requirement would be simply that predicted by our criterion, factored up in proportion to the cube of the rating. The maximum metal temperature would now in general be changed, but the important point is that its value would be independent of the nature of the gas, as shown by equations (1) and (2) since H and ΔT are now fixed. Our criterion is thus still the measure of the influence of gas properties.

It should be noted that when we substitute a better coolant gas, and take advantage of this by raising ratings for the same outlet temperature (the case of most interest), we will in general raise maximum metal temperatures in the process, unless at the same time we change the fin design, and in particular take steps to raise fin efficiency

by thickening, or lowering the fins. This will mean that fins may become vestigial when a very good coolant is used, the consequential loss of cooling surface severely limiting the benefit that could have been got with perfectly conducting fin materials. But this does not alter the fact that gases shown to be better by our simple criterion still remain better. The only new point is that when maximum metal temperature rather than coolant temperature rise is the limitation, the magnitude of the benefit conferred can be much reduced.

Effect on pressure vessel

Another way in which advantage might be taken of a good coolant gas lies in the direction of reducing the required pressure vessel strength. Here the criterion ($M^2c_p^3$) is of direct application for, if the absolute gas pressure is varied as the inverse square root to this quantity, we will keep $\rho^2c_p^3$ constant, and therefore all core and gas temperatures and the pumping power required will remain fixed, for a given power output. Our criterion is thus inversely proportional to the square of the required pressure vessel strength, everything else being the same.

When fins go altogether

We have been concerned exclusively so far with the cooling of circumferentially finned cans, as for reasons already stated, these have a characteristic that permits us to draw general inferences about the choice of coolants. In fact, we have established experimentally that this characteristic is shared even by quite low, widely spaced fins, and it seems that, so long as the surface of the can is so broken up that profile drag predominates over friction, we will have cooling characteristics of the circumferential fin type. This view is strongly supported by recent American data on artificially roughened surfaces, which shows that as roughness is increased, S_t and f become virtually independent of Reynolds Number. Since it is unlikely that the cooling of smooth surfaces will be of anything but academic interest, the present analysis is applicable to any practical gas cooled core design.

Secondary losses

So far we have taken the pumping power to be merely that corresponding to the product of volume and the pressure drop derived directly from the friction coefficient associated with the fin-duct geometry. In practice, the total header-to-header pressure drop is considerably larger than this basic value, by reason of entry and exit losses, and of what is generally termed the acceleration head, which is a fundamental loss associated with the mechanism of heat release to a compressible fluid.

The entry and exit losses cause no confusion to the foregoing arguments, for, since they vary in the same way as the friction loss, their effect is simply got by taking an appropriately larger friction factor in the calculations, which does not effect relative merits of different coolants. The influence of acceleration head is not so immediately obvious, but by putting the expression for this in suitable form, the result may be shown to be the same.

The expression usually quoted for (static) pressure loss in a heated channel, which allows for acceleration heat, is that due to Guggenheim, who integrated the compressible flow equations for the case of a symmetric heat flux distribution. The resulting expression is:

$$\triangle P(2P_1 - \triangle P) = \frac{2fIW^2}{a^2d} \cdot R(T_1 + T_2) + \frac{2W^2R}{a^2} \cdot (\triangle T + T_m \log_e P_1/P_2) \quad \ldots\ldots\ldots\ldots 5$$

substituting, $\left(P_1 - \frac{\triangle P}{2}\right) = P_m$ and $P_m/\rho_m = RT_m$

and noting that for all practical purposes, $\log_e P_1/P_2 = \frac{\triangle P}{P_m}$

the Guggenheim equation becomes:

$$\triangle P = \frac{W^2}{a^2\rho_m}\left[\frac{2fl}{d} + \frac{\triangle T}{T_m} + \frac{\triangle P}{P_m}\right] \quad \ldots\ldots\ldots 6$$

which shows at once that the actual pressure drop is the simple friction one, multiplied by the factor

$$\left[1 + \frac{d}{2fl}\left(\frac{\triangle T}{T_m} + \frac{\triangle P}{P_m}\right)\right]$$

so that again, the nature of the gas does not effect the issue.

In passing it is worth noting that equation (6), which gives the static pressure drop along the channel, may be made to give the more important total head pressure drop by merely halving the values used for the $\triangle T$ and $\triangle P$ terms in the bracket. This extraordinary simple result can be easily derived by adding the difference in entry and exit velocity heads in appropriate terms and simplifying.

Acknowledgement

The experimental work here reported was carried out in the Harwell Engineering laboratory by H. A. Roberts and L. A. Husain, whose collaboration together with that of W. B. Hall of Windscale, is gratefully acknowledged.

References

[1] Calder Hall Symposium, BNEC 1956 Heat Transfer Experiments on the fuel elements—P. Fortescue and W. B. Hall

NOMENCLATURE

k_g	Thermal conductivity of coolant
k_m	Thermal conductivity of fin metal
W	Mass flow rate of coolant
μ	Viscosity
$\triangle T$	Coolant temperature rise
$\triangle P$	Coolant pressure drop
A	Cooling surface area
a	Cooling duct section
l	Cooling duct length
d	Cooling duct hydraulic diameter ($4al/A$)
c_p	Specific heat of coolant
H	Total heat output
h_p	Pumping power
T_{max}	Maximum metal temperature
T_1	Entry coolant temperature
T_2	Exit coolant temperature
P_1	Entry coolant pressure
P_2	Exit coolant pressure
P_m	Mean coolant pressure
V	Velocity
ρ	Density
R	Gas Constant
M	Molecular weight

Derived Groups

G	ρW
R_e	Reynolds Number ($\rho Vd/\mu$)
P_r	Prandtl Number ($c_p\mu/k_g$)
Q	Ratio of l/l', where l' = extrapolated channel length
S_t	Stanton Number ($h/\rho Vc_p$) where h = Surface heat transfer coefficient (based on fin root temp)
S_t'	Stanton Number based on mean *surface* temperature
f	Fanning friction factor $\frac{d}{2\rho V^2} \cdot dp/dl$

Britain is studying several advanced systems for her future power reactors. Here, in outline, is a design study by a team from Harwell of one contender

The Homogeneous Aqueous Reactor

R. HURST GM, MSc, PhD
J. WELLS MSc, MIChemE
D. NEWBY BSc (Eng) AMIMechE

The Homogeneous Aqueous Reactor has many attractions as a power plant. Cost estimates show it would be cheaper both on capital and unit costs than other advanced reactors; the inventory of fissionable material is very low; in principle it is inherently safe and self-regulating in operation. In the two-zone breeder version, once the cycle has been established, it will consume fertile material only. Considerable development work is however still required —particularly on corrosion and pump design—before a homogeneous power reactor could be built to the required standards. After a review of the history of homogeneous reactors the authors go on to describe a design study recently completed at Harwell on a 100MW (elec) two-zone HAR working on the Th-232/U-233 cycle.

THE HOMOGENEOUS AQUEOUS REACTOR is essentially a continuous chemical plant, using a feed of fertile material, producing heat for conversion to electricity as its main product, additional fissionable material as by-product, and fission products as waste.

Fuel can be added continuously and fission products removed under load. This results in a very favourable neutron economy, so that by using a two-zone system it is possible to breed more new U-233 in the blanket than is consumed in the core. The reactor thus operates on a feed of thorium only, after reaching equilibrium, and gives a slight net production of U-233. Also, because of the low neutron absorption by heavy water, the initial charge of fissionable material is much smaller than with liquid metal or fast breeder systems, and because of the high rates of heat transfer which are possible, the power released per kilogram of fissionable material can be higher than that obtained in any other reactor system so far proposed.

The large negative temperature coefficient of reactivity makes it self-controlling and directly responsive to load; it is thus ideal for power generation. The reactor can be allowed to idle and raised to full power very quickly at any time since xenon poison is continuously removed; this simplifies control and avoids poisoning-out.

Many variations of the HAR are possible but the two-zone breeder system operating on the U-233/Th-232 cycle, with heavy water as a moderator and coolant, was considered the most suitable for the production of power on a large scale. The inner zone or core contains the U-233, whilst the outer zone or blanket contains the fertile Th-232 together with some U-233. Most of the power is produced within the core. The fissionable U-233 formed in the blanket is extracted and fed to the core. In general it is advantageous if solutions be used, and for the core a solution of uranyl sulphate has been chosen. In the blanket, however, where concentrations of up to 1000 grams/litre are required, no suitable solution has been found. A slurry has therefore had to be selected and using the preferred material, thorium oxide, the slurry formed is approximately 10 per cent solids by volume.

A flowsheet for the Harwell HAR is given in Fig 1 and the main operating parameters in the table. Some of these have been chosen arbitrarily. Thus the thermal load has been divided 300MW/100MW between core and blanket, and the power density limited to safeguard the core vessel. The diameter of the pressure vessel has been set at 11 ft—about the limit for present fabrication techniques. The blanket thickness was set at 2 ft.

ON CONDUIT À HARWELL une étude sur la construction d'un réacteur homogène aqueux de puissance. Il s'agit d'un réacteur à deux zones, avec la solution UO_2SO_4/D_2O dans le noyau central et le schlamm ThO_2/D_2O dans l'enveloppe. Le rendement électrique total est de 100 MW. Le débit de chaleur dans le noyau central est de 300 MW, et celui dans l'enveloppe est ed 100 MW. L'installation où le combustible est traité continuellement est considérée comme partie intégrale du réacteur. L'avantage d'un tel réacteur consiste en ce qu'il ne brûle que du thorium et par conséquent conserve les matières fissiles. On doit surmonter beaucoup de difficultés d'ordre pratique avant qu'on puisse construire un tel réacteur sans aucun risque.

MAN HAT IN HARWELL eine Konstruktionsarbeit mit einem homogenen Wasser-Kraftreaktor ausgeführt. Es handelt sich um einen Zweizonen-Reaktor mit der UO_2SO_4/D_2O-Lösung im Reaktorkern und dem ThO_2/D_2O-Schlamm im Mantel. Die gesamte elektrische Leistung beträgt 100 MW. Die Wärmeleistung des Reaktorkerns macht 300 MW, die des Mantels 100 MW aus. Die ununterbrochen arbeitende Brennstoffbearbeitungsanlage wird als ein integraler Teil des Reaktors angesehen. Die Überlegenheit eines derartigen Reaktors besteht darin, dass er lediglich Thorium verbrennt, wodurch die Vorräte spaltbarer Stoffe erhalten werden. Bevor man einen solchen Reaktor ohne Gefahr bauen kann, müssen viele praktische Schwierigkeiten überwunden werden.

EN HARWELL se ha llevado a efecto un estudio sobre el diseño de un reactor acuoso homogéneo. Se trata de un reactor de dos zonas con solución UO_2SO_4/D_2O en el núcleo y lechaa ThO_2/D_2O en el colchón. La producción eléctrica total es de 100 MW. El rendimiento térmico es de 300 MW del núcleo y de 100 MW del colchón. Se considera como parte integrante una instalación para la elaboración continua de combustible. La ventaja de esta clase de reactor consiste en que sólo consumiría torio y, por lo tanto, conservaría los suministros de materiales escisibles. Deben superarse muchas dificultades prácticas antes de que un reactor de este tipo pueda construirse con seguridad.

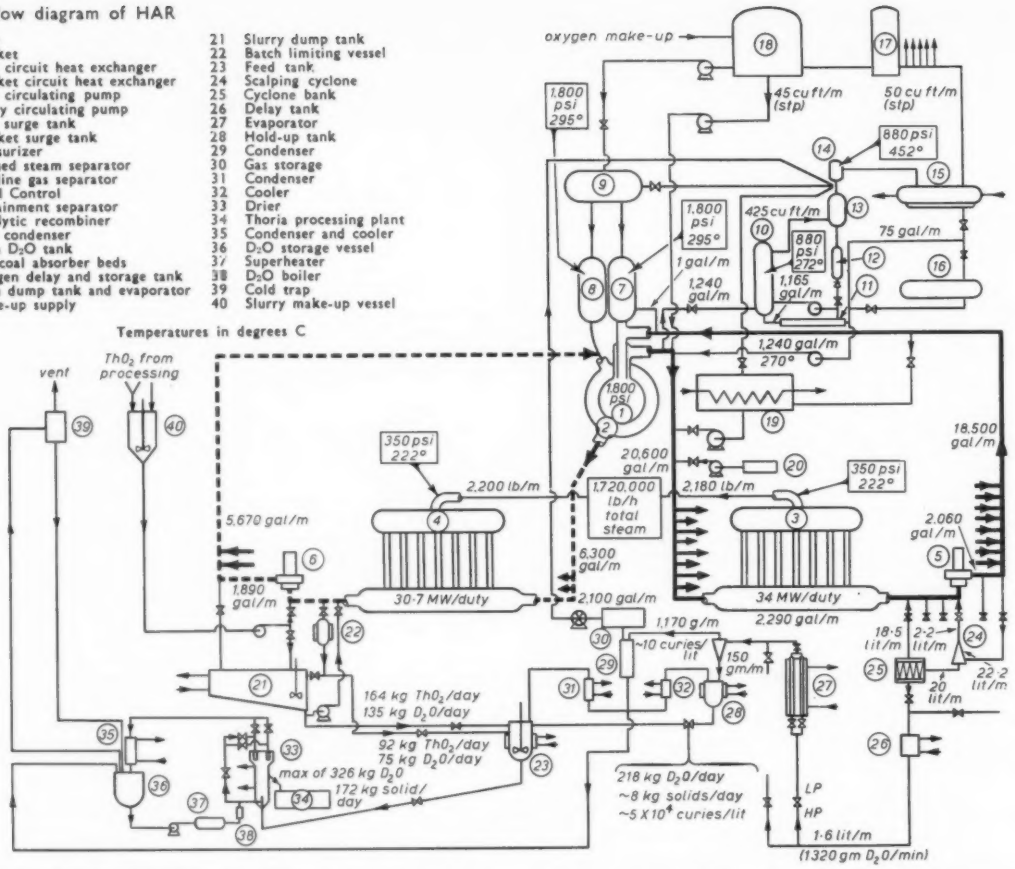
В ХАРВЕЛЛЕ производится исследовательская работа над конструкцией гомогенного вочного энергетического реактора. Это двухзонный реактор с раствором UO_2SO_4/D_2O в активной зонеки со взвесью ThO_2/D_2O в зоне воспроизводства. Полная электрическая мощность равна 100 мегаватт. Тепловая производительность составляет 300 мегаватт в активной зоне и 100 мегаватт в зоне воспроизводства. Установка для непрерывной переработки топлива считается нераздельной частью реактора. Преимуществом реактора этого рода является обстоятельство, что он будет сжигать только торий, сберегая таким образом запас делящихся веществ. Прежде чем будет возможно безопасное строительство такого реактора, придется преодолеть много практических трудностей.

Main circuits

In the main core circuit, the uranyl sulphate leaves the core container and then divides into nine identical circuits. Each of these contains a straight-through, single-pass,

Fig 1 Flow diagram of HAR

1 Core
2 Blanket
3 Core circuit heat exchanger
4 Blanket circuit heat exchanger
5 Fuel circulating pump
6 Slurry circulating pump
7 Core surge tank
8 Blanket surge tank
9 Pressurizer
10 Flashed steam separator
11 Pipeline gas separator
12 Level Control
13 Entrainment separator
14 Catalytic recombiner
15 D_2O condenser
16 Main D_2O tank
17 Charcoal absorber beds
18 Oxygen delay and storage tank
19 Main dump tank and evaporator
20 Make-up supply
21 Slurry dump tank
22 Batch limiting vessel
23 Feed tank
24 Scalping cyclone
25 Cyclone bank
26 Delay tank
27 Evaporator
28 Hold-up tank
29 Condenser
30 Gas storage
31 Condenser
32 Cooler
33 Drier
34 Thoria processing plant
35 Condenser and cooler
36 D_2O storage vessel
37 Superheater
38 D_2O boiler
39 Cold trap
40 Slurry make-up vessel



natural-circulation evaporator designed to remove 35MW of heat from the core solution and generate saturated steam at 350 psi. The solution is circulated by a canned rotor centrifugal pump back to the core vessel. In the slurry circuit the flow divides to pass through three identical circuits. Each contains an evaporator designed to remove 30MW of heat from the slurry and to generate saturated steam at 350 psi. The slurry is returned to the blanket vessel by a canned rotor pump especially designed to exclude slurry from the rotor end.

Abbreviated Specification of Two-zone HAR

Core fluid: 1 g/litre of U-233 as UO_2 SO, dissolved in D-O
Blanket fluid: 1000 g/litre ThO_2 slurry with D_2O

	Core system	Blanket system	Entire system
Diameter, feet	7	11	—
Operating pressure, psi	1800	1800	—
Operating temperatures, °C	240-290	240-290	—
Mean flux in reactor zone, n/cm²/sec	10^{13}	5×10^{15}	—
Circulating rate (mean), igpm	20,000	6000	—
Power density in reactor zone (mean), kW/litre	60	6	—
Thermal load, MW	300	100	400
Electrical output (net), MW	—	—	96
Material inventories (including processing) kg			
U^{233}	40	50	90
Pa^{233}	—	20	20
ThO_2	—	24,000	24,000
D_2O	17,000	20,000	37,000

Gas handling circuit

The gas handling circuit is designed to keep the xenon-135 concentration in the core circuit down to the equivalent poison fraction of 0·01. There is no gas handling circuit for the blanket circuit since the Xe-135 concentration at equilibrium yields an equivalent poison fraction of only 0·011.

A fraction of the core circulation is by-passed through the gas handling circuit, where it undergoes pressure reduction from the main circuit operating pressure of 1800 psi to 880 psi. Partial evaporation produces a fluid mixture of about 2 parts gas and 1 part liquid by volume. A gas mixture containing less than 5 per cent $D_2 + O_2$ is produced and this is considered to be well below the explosive limit. The gas is separated from the liquid and passed through a catalytic recombiner to a condenser which separates the D_2O as liquid from the O_2 and the fission product gases. The gas passes through a series of charcoal absorption beds and is finally returned to the main core circuit. The condensed D_2O is mixed with the concentrate left after the pressure reduction, and the whole pumped back into the main core circuit.

Steam cycle

The power reactor system is regarded as a self-contained breeding system generating its own fuel, and dependent only on the supply of make-up thoria for the blanket. To maintain its independence, a single-pressure saturated steam cycle is envisaged. Bled-steam feed-heating would be used, together with an interstage moisture separator operating at about 30 psia to reduce the wetness of the steam in the low pressure stages.

Start-up and control

After filling the blanket circuit with slurry and the core with heavy water (obtained from evaporation of the core solution) the reactor could be made critical by injection of the concentrated solution, and brought to operating

What is needed before an HAR can be built?

- **A corrosion-resistant, neutron-transparent metal for the core vessel**
- **Pumps for solutions and slurries, capable of running for long periods without attention**
- **Heat exchangers for slurries**
- **A way of removing and replacing highly active components such as pumps, valves and even heat exchangers**
- **A low power reactor experiment for working out control and safety**

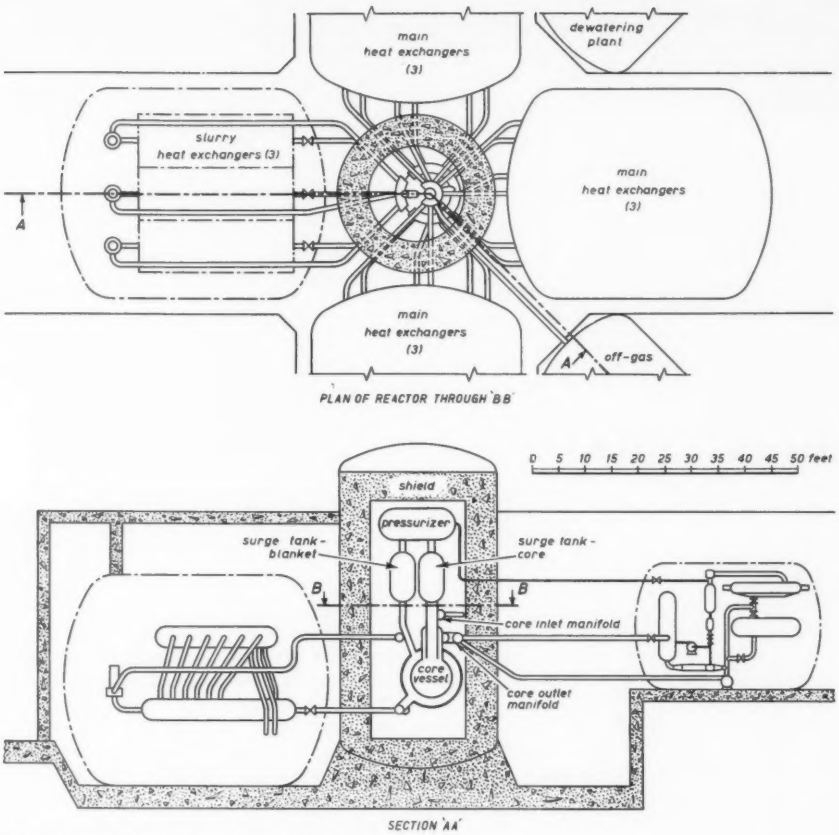


Fig 2 Part of layout shows how all high pressure components are contained in underground pressure vessels

temperature by increasing the uranium concentration. However, if one applies a limitation of constant injection pumping rates for reasons of absolute safety without relying on instrumentation, the rate has to be very low to prevent very high power (surges) at cold criticality. This can be overcome if the heavy water is preheated to about 170° C before injection. The blanket circuit is filled with cold low-pressure slurry from the dump tank. The solution circuit is filled with heavy water by evaporation from the dump tank and the use of the gas circuit condenser, leaving behind a concentrated solution. Pressure is applied to both circuits, the fluids are circulated, and their temperature is raised at a rate limited by thermal stress in the circuit components. As the fluids expand, the overflows are returned to the dump tanks. The reactor is then brought to criticality by gradually mixing the concentrated fuel in the dump tank with the heavy water in the fuel circuit at a controlled rate. This raises the temperature in the core circuit to its operating value by internal power generation, while the blanket fluid temperature follows at a slower rate. The reactor is then ready to be put on load. The complete operation is only required after the main circuits have been emptied for maintenance.

Containment

A diagrammatic layout is shown in Fig 2. Any leak in the high pressure circuit will release fission products into the reactor cell, so complete containment of all high pressure equipment containing active solutions or slurries is necessary. This must be effective in the event of the worst possible contingency, i.e., the instantaneous release of the whole of the reactor contents. The proposed containment takes the form of a number of interconnected cylindrical containers buried several feet below ground, with access to the ends. The vessels are designed to contain the instantaneous pressure rise arising from the release of the total heat content of the reactor system into their free volume.

The seven main containers are connected by large ducts through which the interconnecting pipes pass. These ducts must be large enough to prevent a local build-up of pressure in the central containment vessel in the event of fracture of the core pressure vessel.

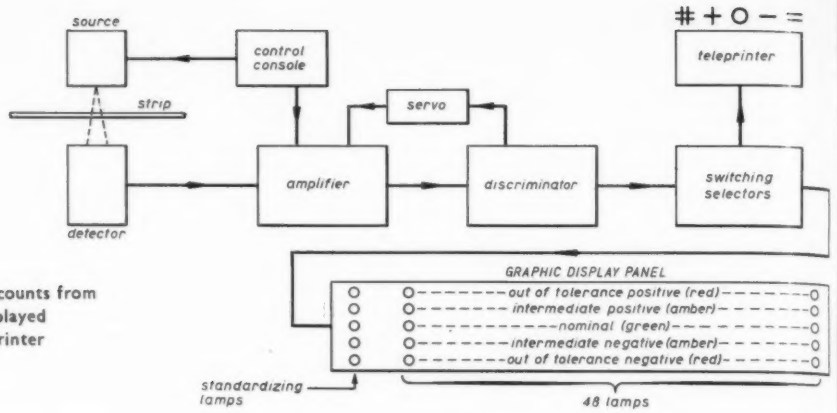
Core processing

The integral core processing circuit is designed to maintain the equivalent poison fraction due to fission and corrosion products at the low level of 0·03. The bulk of the corrosion products will be present in the form of a suspension, and can be separated by a solid-liquid separation technique. The bulk of the non-gaseous fission products will remain in solution and must be separated by chemical processing techniques.

External core and blanket processing

The external processing plant is designed to separate the uranium (U-233), protactinium (Pa-233), thorium and fission products in the blanket. To maintain the atomic percentage of U-233 + Pa-233 in the thorium, at say, 0·4 per cent a processing rate of about 100 kg thoria/day is required. A fraction of the core solution, derived from integral processing, is added to this thoria and processed simultaneously. The flowsheet for the plant is based on conventional solvent extraction methods.

This article is a shortened version of a lecture given to the Institution of Chemical Engineers in London on April 2, 1957



Block schematic shows how integrated counts from detector are sorted into five levels, displayed on graphic panel and recorded on teleprinter

Bremsstrahlung source for continuous th

A NUCLEONIC thickness gauge designed and manufactured by Baldwin Instrument Co Ltd, Dartford, Kent, was recently installed on a hot strip rolling mill at the Rotherham works of Steel, Peech and Tozer Ltd—one of the United Steel companies. This is said to be the first unit of its kind in continuous use in this country. Last month NUCLEAR POWER visited the works to see the installation working on normal production.

The mill is designed for rolling strip up to 9in. wide 0·03 to 0·25in. thick and, although by no means new, it is one of the fastest producers of this size in the country. After a preliminary reduction, the strip is finished in a range of six two-high stands and is then turned on to its edge between a pair of water-cooled guides. In this position it passes the thickness gauge on its way to the run out conveyor, at the end of which it is coiled.

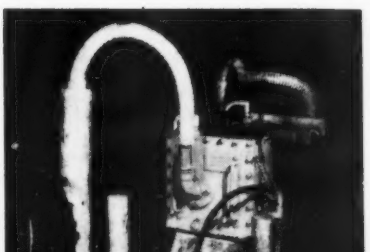
Visual indication

The main requirement for the gauging installation was that it should provide immediate visual indication of the thickness profile along the strip so that adjustments to the furnace, or to the rolls can be done without delay. In addition, it was required to have a permanent record of each strip profile and this has been accomplished by a teleprinter. Finally, since the source and detection units had to work in close proximity to a red-hot strip moving at about 30 mph accompanied by a considerable amount of cooling water and vibration, all the components and circuitry had to be designed to be as rugged and reliable as possible.

A pictorial representation of the longitudinal profile of the strip is indicated on a graphic panel, easily visible by the foreman and operators. This comprises five horizontal rows of 48 lamps. The middle row in green indicates that the strip is well within limits. The adjacent rows (amber) mean just inside tolerance, and the outermost rows (red) signify that the strip is beyond the limits. The limits can be set on the instrument to suit the rolling specification, which is usually in the region of 0·002 to 0·010in. The apparatus works on an integrating cycle and each lamp lit on the panel represents the mean thickness of the portion of strip passing the measuring head in 1 second. In addition, a teleprinter takes a permanent record of each strip in terms of the following signs: # + 0 − =, the signs corresponding to the coloured lamps. The equipment comprises five main units: source, detector, electronics cabinet, operator's control desk and teleprinter, and graphic display board.

Fission product source

The source used is fission-product strontium-90 (½-life 28y) which is supplied to special order by the Radiochemical Centre, Amersham. The isotope is silver-encapsulated and contained in a square holder similar to the type supplied for clinical work. In this particular installation, the gap between source and detector is about 9in. and the source strength is of the order of a few hundred millicuries. Baldwin's are at present preparing a somewhat similar installation for a new strip mill at Steel, Peech and Tozer's Brinsworth works. In this, the gap will be about 15in. and owing to the operation of the inverse square law, the source strength will of course be correspondingly greater. It is found that the position of the strip between source and detector is not critical over quite a large range. The source capsule is located in a two-piece cylindrical lead container about



Source unit (nearest camera) is enclosed in water-jacketed casing. Beyond the strip-guide is a detector, similarly cooled

2½in. dia and about the same height, with an aluminium alloy window at one end. The radiations used are actually *Bremsstrahlung*, or secondary X-rays, which are produced by slowing down in the capsule and window metal of beta particles (2·24 MeV) emanating from the yttrium-90 daughter product of the strontium-90. When not in use, the window may be shut by sliding over it a steel plate.

The source unit also contains a standardizing device. This consists of a disc of standard thickness which is brought in front of the source between successive strips. The instrument measures the accurately known thickness of this disc and automatically corrects any drift present so that the circuit is ready calibrated for the next pass. There are actually twelve of these discs—two each of

Seven inch strip leaves the finishing rolls at high speed. The thickness gauge head unit is protected against 'cobbles' by steel housing (centre)

thickness measurement in hot strip mill

six thicknesses—mounted on a wheel which is moved bodily by a pneumatic actuator over the source window during the standardizing operation. Selection of the appropriate disc is made from the control desk but once selected, it is automatically brought in front of the source the moment a strip has passed. The whole of the source unit is contained in a cast steel casing with a water-cooled jacket.

After passing through the moving strip the attenuated radiation falls on a thallium-activated sodium iodide crystal, scintillations in which are picked up by a standard EMI photomultiplier tube fixed on antivibration mountings.

Both source and detector units are easily separated for maintenance and may also be traversed across the width of the strip by means of a pneumatic cylinder with accurate position control, regulated from the control desk.

The main electronics cabinet is situated in the roll motor room. Pulses from the photomultiplier tube pass through a head amplifier to a discriminator in which a capacitor is charged over the 1 second measuring cycle. The voltage across this capacitor at the end of the period is proportional to the mean thickness of the length of strip which has passed through in the time. At the end of the time the charge is shared with another capacitor and compared electronically with a standard potential. The error signal is then fed to a set of biased amplifier valves which discriminate between the five levels: out of tolerance positive, intermediate positive, nominal, intermediate negative, out of tolerance negative. These five levels are represented by five banks of a 50-contact uniselector which switches at 1 second intervals. The integrated count from each cycle is thus passed to the appropriate bank and through a relay to the particular lamp due to be lit. The timing gear takes the form of a set of microswitches operated by chrome steel cams on a common shaft driven by a synchronous motor. This timing gear also controls the standardizing circuit servo. The lamps on the board remain lit until the moment the leading edge of the next strip arrives at the source, at which time the old display is cancelled.

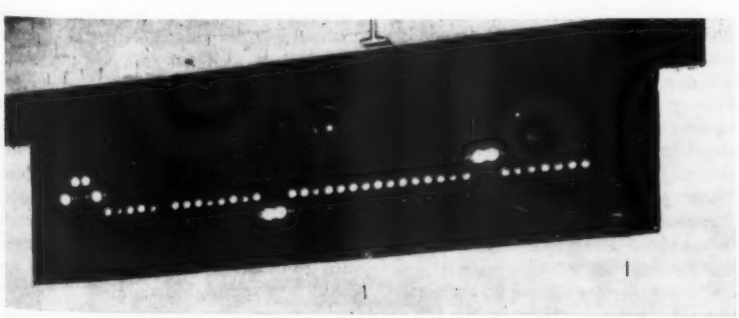
The control desk includes a set thickness control, range selector switch for preselecting the standardizing disc, alloy switch for use with different melts and tolerance control for setting the maximum and minimum allowable.

Automatic drift correction

In the detection head there are actually two photomultiplier tubes, the second being used to operate the standardizing circuit. When the trailing edge of a strip clears the measuring head there is a sudden increase in the radiation reaching the crystal. This acts on the second tube and a feed-back servo circuit switches the circuit to 'standardize', at the same time bringing the appropriate standard thickness disc in front of the source window. If there has been any drift, it is automatically corrected by a potentiometer. The standardizing process is also displayed on a set of five lamps on the display panel. When the leading edge of the next strip reaches the source the process is reversed and the circuit recommences to 'measure'.

Throughout, greatest attention has been paid to reliability and rapid rectification of faults should they occur. Apart from the usual test meters and switches, means are provided for testing various portions of the equipment without the use of other main units. For example, if a fault is supected in the control desk, it can rapidly be isolated and a built-in test facility brought into circuit. As a further aid to simple maintenance, certain components such as uniselectors and relays are plug-in replaceable units.

Typical display on graphic panel shows a strip out of tolerance at the leading edge with two short minor divergencies further along

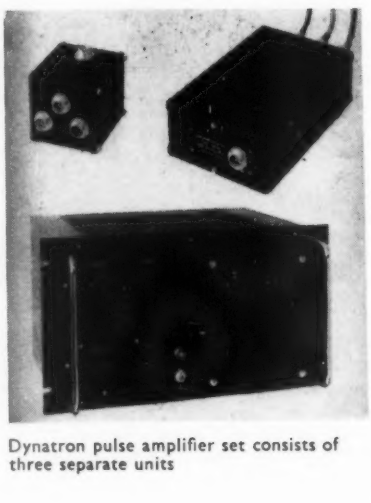


EQUIPMENT

A wide-band linear amplifier for ion chambers, counters

The Nucleonic and Electronics department of Dynatron Radio have announced the introduction of pulse amplifier, Type 1430A, to their range of instruments. The instrument is a wide band linear amplifier designed for use with fast ionization chambers, proportional and scintillation counters. This equipment comprises three units; main amplifier and stabilized power supplies, h.f. head amplifier for ionization chambers and proportional counters and an alternative cathode follower head for scintillation counters.

The main amplifier has a maximum gain of 86db reduceable in steps of 2db to a gain of 46db with an input impedance of 100 ohms. It will deliver output pulses of 50 volts positive polarity for not greater than 1% non-linearity.



Dynatron pulse amplifier set consists of three separate units

Integrating and differentiating time constants are selected by controls over the ranges of I.T.C.O.08μs to 8μs in 7 steps and D.T.C.O.08μs to 8μs in 7 steps plus 250μs step The h.f. head amplifier has a fixed gain of 31·5db and provision for input of either polarity. The alternative cathode follower head unit has an insertion loss of 23db and also has provision for input of either polarity. Both these head units incorporate e.h.t. filter circuits.

H.t. and l.t. supplies for the whole equipment are stabilized and the amplifier circuits incorporate negative feedback enabling a gain stability of the order of 1%.

Dynatron Radio Ltd, The Firs, Castle Hill Maidenhead, Berks

a.c. voltage stabilizers for outputs up to 5kVA

A range of a.c. voltage stabilizers, with outputs from 300VA to 5kVA, has been introduced by Philips. Designed for use with any laboratory or industrial equipment requiring a constant input voltage they were shown for the first time at last month's Electrical Engineers Exhibition, in London.

In the 300VA type, stabilization is by two transformers in series, the first having an unsaturated and the second a saturated core. A capacitor is fitted to compensate for load variations. Models are available for 50 or 60 c/s working at 220V nominal input. The output is within ±1% of 220V for mains fluctuations from −15% to +10%. Simple in construction and with no moving parts to require maintenance, this equipment weighs only 39 lb, measures 14½″ x 8″ x 7″ and is available in chassis or cased form for either vertical or horizontal mounting.

Output voltages of the 1, 1.5, 2 and 5kVA equipment are controlled by a transductor in series with part of the main transformer winding, any slight variation in secondary voltage being eliminated by a bridge circuit and amplifier. A safety relay automatically reduces the secondary voltage if this rises above a certain level. These stabilizers are available for either 110, 127 or 220V nominal input at 50 c/s (also 60 c/s in the case of the 5kVA model). Variations in the mains voltage from −15% to +10% and of ±3% in frequency are permissible for an output within ±0.2% of the nominal voltage. For the 1.5kVA model, mains voltage fluctuations can be from −30% to +10%.

Philips Electrical Ltd,
Century House, Shaftesbury Avenue,
London, WC2

Angled front gives maximum accessibility in laboratory glove box

The entire top of the Towers glove box is removable

A glove box suitable for laboratory use is manufactured by J. W. Towers & Co Ltd. This was originally developed for handling alpha- or beta-active compounds such as C-14. Operations such as grinding, stirring, filtering, gentle heating etc. may be carried out under controlled conditions. Toxic materials may be handled in dry powder form without the danger of particles becoming airborne. Hygroscopic substances such as P_2O_5, PCl_5, sodium metal etc, can be handled in controlled atmospheres.

The box is constructed of sheet steel, rustproofed and stove enamelled. The entire sloping top is of transparent plastic which is easily removable by undoing the wing nuts. Another similar window is situated on the horizontal part of the top and a tubular lamp may be placed over this to provide illumination. The glove holes are situated on the front of the box which is in two parts meeting at an angle: this provides maximum accessibility to all parts of the box. On one side is an air lock through which apparatus and materials can be introduced. Inside is a removable stainless steel tray.

Other features of the box are: connections for mains and low voltage electricity, brass stopcocks for the control inlet and exit of dry air or other gases, blanked-off holes for other services such as exhaust, vacuum, filtration tube etc. Dimensions: 26 in. long, 22 in. maximum depth, 14 in. max. height. The airlock chamber is 6 by 6 by 8 in. high.

W. J. Towers & Co Ltd, Widnes, Lancs.

Fully automatic photomicrography

A new Zeiss automatic camera microscope with wide scientific, medical and industrial applications will shortly be available in this country. Known as the *Ultraphot II*, the instrument is suitable for visual observation as well as photomicrography and in addition it can be used for microprojection, making it particularly valuable for instruction purposes. For metallurgical work, special wide-angle objectives are available.

An outstanding feature of the *Ultraphot II* is the fully automatic photographic mechanism, which entirely eliminates the difficulties of computing exposures. A single push-button opens the

Zeiss Ultraphot II can also be used for visual work

camera shutter and the exposure time is then adjusted automatically to the correct value for the intensity of illumination. The shutter closes automatically after the correct exposure. Bright field and dark field methods and phase contrast technique with either trans- or epi-illumination, employing polarized or non-polarized light, may all be readily used.

United Kingdom agents: Degenhardt & Co, 32 Maddox Street, London, W1

Vapour removal from vacuum pumps

One of the principal causes of deterioration in the performance of high vacuum pumps is contamination by process vapours, of which water is by far the most common. To overcome the problem Pulsometer rotary high vacuum pumps can be fitted with air injection scavenging and by means of this method most condensable vapours can be handled to a greater or lesser degree, depending upon their volatility.

Scavenging air which enters the cylinder after the rotor blade has isolated the suction port, can support a substantial

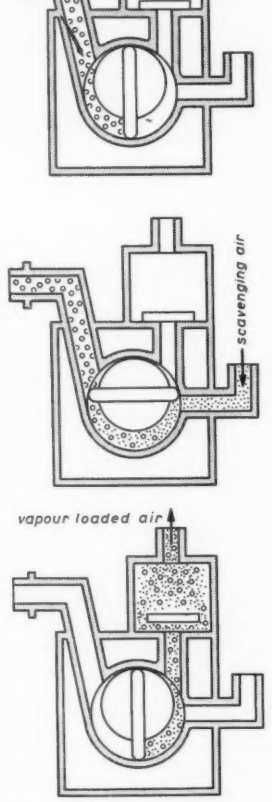


Diagram shows how fresh air is used to take up vapour

quantity of water vapour without condensation occurring—particularly when the mixture is raised in temperature as a result of the pump's discharge action. For instance, if a discharge temperature of the order of 195°F is assumed then each cubic ft of injected air will carry ·0265 lb of water with it.

It is usual to limit the amount of injected air to a maximum of 10% of the nominal swept volume of the pump, so that a 100 cu. ft/min pump will handle ¼ lb of water per minute. The required discharge temperature is attained on the larger pumps by restricting the flow of cooling water but some models may need heating and the provision of slight back pressure.

Working against full air injection at a maximum temperature the pumps will maintain a high degree of vacuum from 0·1 mm to 0·3 mm depending on the particular model but with reduced amounts of injection and more normal temperatures high degress of vacuum are achieved down to the normal ultimates of the pumps involved.

In cases where pumps are dealing with varying conditions which temporarily increase the through-put of water beyond the maximum air injection, auxiliary settling tanks are necessary. In addition it is often necessary to guard against condensation from the exhaust pipe draining back into the pump and pipework installations should take this fact into account.

It should be noted that air injection scavenging cannot be used on circuits where the suction pressure is greater than approximately 8 in. Hg absolute (203 mm Hg).

The Pulsometer Engineering Co Ltd, Nine Elms Iron Works, Reading, Berks

12-channel remote control on one circuit

A d.c. *Multiplexing* equipment has been developed by GEC for the continuous indication, at a central control point, of the operating state of apparatus situated in remote locations. Information from up to twelve such items of equipment can be relayed to the control along only a single pair of wires; previously, a pair was needed for each unit to be monitored. This can mean a considerable cost saving.

Originally designed for monitoring airfield control lights, the equipment can be applied to many other types of installation where it is necessary to check quickly the operating state of equipment remote from the control point.

The transistorized equipment consists of up to twelve transmitter units and a cabinet containing the corresponding receiver sub-units. Each of the transmitter units is an audio-frequency oscillator tuned to a different frequency. These units are distributed along the wires so that one is adjacent to each point to be monitored. The receiver sub-units all comprise a band-pass filter, amplifier, detector and relay. Each band-

pass filter is tuned to a particular transmitter frequency.

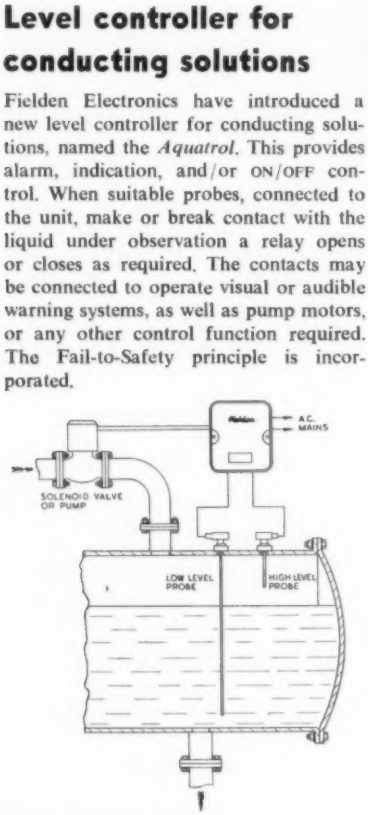
Any operation of the equipment being monitored can be arranged to switch the adjacent monitoring transmitter. At the presence of a particular oscillator tone on the wires, the relay in the corresponding receiver then operates and, by a suitable circuit, can be used to show which transmitter is working. For example, the extinguishing of an essential warning light can be signalled by the disappearance of the associated oscillator tone from the receiver.

The equipment which will operate over a wide range of temperatures and humidity, can be used to relay signals along wires of up to 5 miles in length.

The General Electric Co Ltd.
Magnet House, Kingsway, London, WC2

Level controller for conducting solutions

Fielden Electronics have introduced a new level controller for conducting solutions, named the *Aquatrol*. This provides alarm, indication, and/or ON/OFF control. When suitable probes, connected to the unit, make or break contact with the liquid under observation a relay opens or closes as required. The contacts may be connected to operate visual or audible warning systems, as well as pump motors, or any other control function required. The Fail-to-Safety principle is incorporated.



Typical Aquatrol installation in closed tank

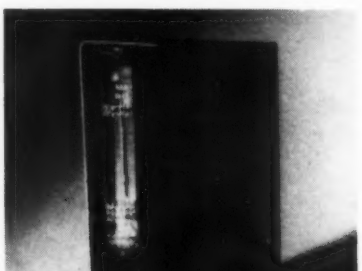
The figure shows schematically a typical installation for control of a solenoid valve. According to the level of the liquid in the tank the *Aquatrol* relay activates the solenoid valve or pump, opening it or closing it as the occasion demands. The normal hold-on circuit required when using solenoid valves is incorporated in the instrument, thus removing the necessity for extra relays.

Fielden Electronics Ltd.
Wythenshawe, Manchester

Miniaturized quartz crystal oscillator

The latest transistorized product by Venner Electronics is the Crystal Oscillator type TS5. This packaged unit provides two outputs, one sine and one square, at a frequency of 10 kc/s. An XY flexure quartz crystal is used to provide accurate control, a preset condenser being used externally to the block for initial setting of the oscillator frequency. The circuit is encapsulated in synthetic resin with the exception of the crystal, which is replaceable.

The oscillator may be used with two types of crystal, one having a zero temperature coefficient between 15°C and 20°C so that maximum accuracy is obtained at room temperature, and the other a zero temperature coefficient between 40°C and 50°C for applications where the ambient temperature is of this order. The stability of the oscillator at or about the point at where the zero temperature coefficient occurs is of the order of 3 parts in 10^6.



Whole unit, except for crystal, is encapsulated

The supply voltage is nominally 10 but the stage will function satisfactorily with supplies from 12V to 4V. The output voltage on square is approximately 7.5V peak-to-peak with a 10V supply, and on sine approximately 5.6V peak-to-peak. A low impedance output is provided for the squarewave via an emitter follower and provision is made for gating.

The unit is suitable for directly feeding the Venner Decade Counter and Scaler, type TS10, and the Binary Unit, type TS2, from which many types of frequency and time reference, time delay and time measuring equipment can be constructed.

Venner Electronics Ltd.
Kingston By-Pass, New Malden, Surrey

Level switch works on heat transfer

A new liquid level switch of advanced design has been developed by Teddington for the control and indication of liquid level in tanks, boilers, and all types of industrial vessels.

Operating on an entirely new principle, the type WX has no moving parts yet is capable of switching loads up to 5 amps at 250V a.c. without subsidiary amplifiers or relays, and is particularly suitable for installation where the interior of the vessel being controlled is not readily accessible for cleaning or repairs since it requires no maintenance whatsoever.

The switch is a thermal instrument operating on a difference in heat transfer between the sensitive element and the liquid in the vessel, or the sensitive element and the vapour; not on the difference in temperature or latent heat.

This principle (protected by UK Patent 565,309) gives a very sensitive response, changes of level in the order of $\frac{1}{2}$in. being sufficient to operate the switch. The operating mechanism is temperature compensated and the instrument is therefore unaffected by temperatures from 0 to 350°F.

It also provides an automatic surge damping effect since a positive change in level of sufficient duration to affect the heat transfer rate is necessary before the switch will operate. This entirely eliminates short-cycling caused by momentary changes in level, which is an important advantage in installations normally subject to surging or vibration. Two models are available offering alternative methods of mounting.

Switch is temperature compensated from 0 to 350°F

Teddington Industrial Equipment Ltd.
Sunbury-on-Thames, Middx

The concluding article in NUCLEAR POWER'S basic course deals with reactor kinetics, or behaviour under unsteady conditions

Reactor Physics—12

JAMES F. HILL
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1. Introduction

We now wish to study the behaviour of the neutron population in a reactor as a function of the time when the reactor is not in a steady state. By neutron population is meant the total number of neutrons in the reactor and this is therefore proportional to the reactor power.

As will be seen later, the time behaviour of a reactor is largely governed by the delayed neutrons, and in order to appreciate their importance we shall first study the kinetics of a reactor assuming there are no delayed neutrons. In the simple treatment given here, all the neutrons will be assumed to be thermal.

2. Reactor kinetics without delayed neutrons

Because we shall use the total number of neutrons in the reactor as a variable, we shall deal with the neutron leakage by the use of the effective multiplication constant k_e defined as

$$\frac{k}{k_e} = \frac{\text{neutrons absorbed in the reactor} + \text{neutrons escaping from the reactor}}{\text{neutrons absorbed in the reactor}} \qquad (12.1)$$

so

$$\frac{k}{k_e} = 1 + \frac{\text{neutrons escaping from the reactor}}{\text{neutrons absorbed in the reactor}} \qquad (12.2)$$

The second term on the right of this equation is the leakage as usually defined, so putting

$$\frac{\text{neutrons escaping from the reactor}}{\text{neutrons absorbed in the reactor}} = l \qquad (12.3)$$

then

$$k = k_e(1 + l) \qquad (12.4)$$

Then for a reactor, if n is the total number of neutrons in the reactor,

$$\frac{dn}{dt} = \text{rate of change of the number of neutrons}$$
$$= \text{rate of production of neutrons}$$
$$- \text{rate of escape of neutrons}$$
$$- \text{rate of absorption of neutrons} \qquad (12.5)$$

or

$$\frac{dn}{dt} = \text{rate of absorption}\left[\frac{\text{production}}{\text{absorption}} - \frac{\text{escape}}{\text{absorption}} - 1\right] \qquad (12.6)$$

Now the rate of absorption is

$$nv\Sigma_a = \frac{nv}{\lambda_a} = \frac{n}{\tau_0} \qquad (12.7)$$

where v is the neutron velocity and Σ_a the absorption cross-section per unit volume of the core material, λ_a the absorption

ON CONSIDÈRE d'abord l'allure cinétique d'un réacteur pour le simple cas où l'on suppose l'absence des neutrons retardés. Ensuite on introduit l'effet des neutrons retardés et l'on observe de quelle manière ils diminuent la vitesse du changement de la puissance du réacteur. On montre aussi que, finalement, la variation de la puissance avec le temps acquiert une forme exponentielle. En cas où la période du réacteur (le temps au cours duquel la puissance augmente ou diminue e fois) est très courte, on trouve que le réacteur se comporte comme s'il n'y avait pas de neutrons retardés. On trouve aussi, pour des périodes du réacteur très longues, une relation simple entre cette période et la réactivité induite dans le réacteur.

MAN UNTERSUCHT ZUERST das kinetische Verhalten eines Reaktors für den einfachen Fall, in welchem angenommen wird, dass keine verzögerten Neutronen vorhanden sind. Dann wird der Effekt der verzögerten Neutronen eingeführt und man beobachtet, wie dieselben die Leistungsveränderungsrate des Reaktors ernirdrigen. Man zeigt zugleich, dass die Abhängigkeit des Leistungsverlaufes von der Zeit schliesslich eine exponentielle Form annimmt. Falls die Reaktorperiode (die Zeit, in welcher die Leistung e-mal grösser oder kleiner wird) sehr klein ist, verhält sich der Reaktor, als ob keine verzögerten Neutronen vorhanden wären. Ferner findet man für sehr grosse Reaktorperioden eine einfache Beziehung zwischen der Periode und der im Reaktor induzierten Reaktivität.

SE CONSIDERA PRIMERO el comportamiento cinético de un reactor en el simple caso de suponer que no hay presentes neutrones retardados. Después se introduce el efecto de estos últimos y se observa en qué manera ellos reducen el régimen del cambio de potencia del reactor. También se comprueba que el cambio de potencia con el tiempo es, finalmente, exponencial en forma. En el caso en que el período del reactor es muy corto (el período del reactor es el tiempo que tarda la potencia en cambiar por un factor de e) compruébase que el reactor se comporta como si no hubieran presentes neutrones retardadas. Igualmente, para períodos muy largos del reactor, se descubre una simple relación entre el período y la reactividad inducida en el reactor.

СНАЧАЛА РАССМАТРИВАЕТСЯ режим реактора для простого слуная, в котором предполагается отсутствие запаздывающих нейтронов. Затем принимается во внимание эффект запаздывающих нейтронов и находится, в какой степени они уменьшают темп изменения мощности реактора. Доказывается также, что, в конечном счете, изменение мощности во времени происходит согласно показательной функции. Если период реактора (время, в течение которого мощность увеличивается или уменьшается в ё раз) очень мал, то оказывается, что режим нейтрона таков, как будто бы запаздывающих нейтронов совсем не было. Для очень долгих периодов реактора находится соотношение между периодом и реактивностью, индуцированной в реакторе.

mean free path in the core material and τ_0 the mean lifetime of the neutrons in an infinite mass of the core material as

$$\tau_0 = \frac{\lambda_a}{v} \tag{12.8}$$

By the definition of k,

$$k = \frac{\text{neutron production}}{\text{neutron absorption}} \tag{12.9}$$

and as shown above in (12.2)

$$\frac{k}{k_e} - 1 = \frac{\text{escape}}{\text{absorption}} \tag{12.10}$$

So, combining (12.7), (12.9) and (12.10) in (12.6) leads to

$$\frac{dn}{dt} = \frac{nk(k_e - 1)}{\tau_0 k_e} \tag{12.11}$$

Then integrating (12.11) gives

$$n = n_0 \exp\left(\frac{k_e - 1}{k_e}\right)\frac{kt}{\tau_0} \tag{12.12}$$

where n_0 is the number of neutrons in the reactor at time $t = 0$.

We introduce a quantity ρ, called the reactivity, defined by

$$\rho = \frac{k_e - 1}{k_e} \tag{12.13}$$

The significance of ρ will be demonstrated later. Then (12.12) becomes

$$n = n_0 \exp \frac{\rho k t}{\tau_0} \tag{12.14}$$

Then, (12.14) shows that for a given value of ρ, that is of k_e, the number of neutrons varies exponentially, increasing if ρ is positive and decreasing if ρ is negative. Thus if ρ is positive, k_e is greater than unity and the reactor is divergent. Similarly $k_e < 1$ means the reactor is sub-critical, and if $\rho = 0$, that is $k_e = 1$, $dn/dt = 0$ so the reactor is critical.

The above analysis is not strictly true when there is an independent neutron source present in a reactor. Such a source is the spontaneous neutrons from the U-238. (U-238 undergoes $6{\cdot}9 \times 10^{-3}$ spontaneous fissions per sec per gram.) In this case (12.11) becomes

$$\frac{dn}{dt} = \frac{nk}{\tau_0 k_e}(k_e - 1) + S = \frac{\rho nk}{\tau_0} + S \tag{12.15}$$

where S is the total number of spontaneous neutrons produced per sec.
Then

$$n + \frac{S\tau_0}{k\rho} = \left(n_0 + \frac{S\tau_0}{k\rho}\right) exp\, \frac{\rho k t}{\tau_0} \tag{12.16}$$

Again in general if $\rho < 0$, n decreases exponentially, and if $\rho < 0$, n increases exponentially. However, in this case if $\rho = 0$, that is $k_e = 1$, from (12.15).

$$\frac{dn}{dt} = S \tag{12.17}$$

so that

$$n = n_0 + St \tag{12.18}$$

and n therefore increases linearly with time, and so $k_e = 1$ is not exactly the condition for criticality in this case. The exact condition is, of course, obtained by putting $dn/dt = 0$ in (12.15). Then, for critical

$$n = -\frac{S\tau_0}{k\rho} \tag{12.19}$$

and so n and ρ are related by this condition in a critical reactor. That is, k_e depends on the number of neutrons in the reactor, and as n is positive, $k_e < 1$. In practice, k_e will be very nearly equal to unity for a reactor running at any reasonable power, so in general the condition that $k_e = 1$ for critical is sufficiently accurate.

As an example, suppose a reactor is running at 1 watt of heat. This is equivalent to $3{\cdot}1 \times 10^{10}$ fissions per sec or $3{\cdot}1 \times 10^{10}\nu$ neutrons. Now in a typical graphite uranium reactor, τ_0 will be about $1{\cdot}5 \times 10^{-3}$ sec and so the number of neutrons in the reactor will be, taking $\nu = 2{\cdot}5$

$$n = 3{\cdot}1 \times 10^{10} \times \nu\tau_0 \times 1{\cdot}5 \times 10^{-3} = 4{\cdot}65 \times 10^{7}\nu \tag{12.20}$$

Now if there are say 30 tonnes of natural uranium in the reactor, the number of spontaneous fissions per sec S' will be approximately — using the figure for U-238 given above

$$S' = 30 \times 10^{6} \times 6{\cdot}9 \times 10^{-3}\,\nu \tag{12.21}$$

Then from (12.18)

$$3{\cdot}1 \times 10^{10}\nu\tau_0 = -\frac{30 \times 10^{6} \times 6{\cdot}9 \times 10^{-3}\nu\tau_0}{k\rho} \tag{12.22}$$

$$\therefore \quad \rho = \frac{k_e - 1}{k_e} = -\frac{3 \times 6{\cdot}9 \times 10^{4}}{3{\cdot}1 \times 10^{10}\,k} \tag{12.23}$$

and putting $k = 1$ approximately, this gives

$$k_e \simeq 1 - 6{\cdot}7 \times 10^{-6} \tag{12.24}$$

We now return to the simple form (12.14).
In a reactor with $k \simeq 1$, $\tau_0 = 1{\cdot}5 \times 10^{-3}$ sec then

$$n = n_0 \exp\left(\frac{\rho t}{1{\cdot}5 \times 10^{-3}}\right) \tag{12.25}$$

So if ρ is suddenly increased from zero to say $1{\cdot}5 \times 10^{-3}$ then the reactor power will rise by a factor of e in one second, and after n seconds will have risen by a factor e^n.

In a reactor in which τ_0 is much smaller, for example a fast reactor where τ_0 may be 10^{-7} sec, then the time for the power to multiply by a given factor will be correspondingly shorter. For example, after one second with this value of τ_0 and $\rho = 1{\cdot}5 \times 10^{-3}$

$$\frac{n}{n_0} = exp\left(\frac{1{\cdot}5 \times 10^{-3}}{10^{-7}}\right) = exp\,(1{\cdot}5 \times 10^{4}) \tag{12.26}$$

The time taken for the reactor power to rise by a factor of e is often called the reactor period.

However, this comparison and these values of n/n_0 give a completely false picture of the kinetic behaviour of a reactor. This is because the presence of the delayed neutrons has been neglected. We now proceed to take these into account.

3. Reactor kinetics with delayed neutrons

The above analysis has assumed that all the neutrons produced in fission effectively appear instantaneously. This however is not the case. A small fraction appear at appreciable intervals after fission, being emitted in the decay processes of some fission products. There are several groups of these and because each group is associated with a particular fission decay the various delayed neutron groups have associated half-lives corresponding to the decay of the fission product. Further, different fractions of delayed neutrons are produced in each group.

Characteristics of the delayed neutron groups arising from the thermal fission of U-235 are given in Table 12.1.

Group	T_j	τ_j	μ_j
1	54·3	78·3	0·036
2	21·7	31·3	0·210
3	5·87	8·47	0·192
4	2·18	3·15	0·409
5	0·46	0·66	0·135
6	0·13	0·19	0·018

Table 12.1. *Delayed neutrons from the thermal fission of U-235**

In the table T_j and τ_j which are quoted in seconds are respectively the half-lives and mean-lives ($\tau_j = T_j/\ln 2$) associated with the different groups and μ_j is the fraction of delayed neutrons of group j, so that $\Sigma_j \mu_j = 1$. The total fraction of all neutrons which are delayed for this case is $c = 0{\cdot}00703$.

The most obvious effect the delayed neutrons have is, in effect, to increase the mean neutron lifetime τ_0 to a value τ_0' where

$$\tau_0' = \tau_0 + c \sum_j \mu_j \tau_j \tag{12.27}$$

which in the particular case of, say, $\tau_0 = 1{\cdot}5 \times 10^{-3}$ sec gives

$$\tau_0' = 1{\cdot}5 \times 10^{-3} + 8{\cdot}7 \times 10^{-3} = 88{\cdot}5 \times 10^{-3} \text{ sec} \tag{12.28}$$

Two points are to be noted from this result.

Firstly the value of τ_0' is determined almost wholly by the delayed neutrons.

Secondly if τ_0' is used instead of τ_0 in (12.14), after 1 second, for $\rho = 1{\cdot}5 \times 10^{-3}$

$$\frac{n}{n_0} = exp\left(\frac{1{\cdot}5 \times 10^{-3}}{88{\cdot}5 \times 10^{-3}}\right) = exp\, 0{\cdot}0017 = 1{\cdot}0017 \tag{12.29}$$

demonstrating the effect of the delayed neutrons on slowing up the rate of power rise.

4. Formulation of the equations with delayed neutrons

If r_j denotes the number of nuclei in the reactor which give rise to a delayed neutron of type j, then the rate of change of r_j, dr_j/dt, is the rate of production of r_j minus its rate of decay. Now each delayed neutron of type j produced corresponds to a nucleus of type j, and so the rate of production of r_j is the rate of production of delayed neutrons of type j. The rate of absorption of neutrons is $\Sigma_a nv = n/\tau_0$, and so the rate of production is kn/τ_0 of which a fraction c are delayed and a further fraction μ_j belong to type j. The rate of decay is given by the ordinary radioactive decay, namely $r_j/\tau_j = \lambda_j r_j$ where $\tau_j^{-1} = \lambda_j$. So finally

$$\frac{dr_j}{dt} = \frac{knc\mu_j}{\tau_0} - \lambda_j r_j \tag{12.30}$$

with

$j = 1$ to 6 for the six delayed neutron groups

For n we have the equation

$$\begin{aligned} \frac{dn}{dt} = &\text{ rate of production of prompt neutrons (including neutron sources)} \\ &+ \text{ rate of production of delayed neutrons} \\ &- \text{ rate of capture of all neutrons} \\ &- \text{ rate of escape of all neutrons} \end{aligned} \tag{12.31}$$

*This data is taken from ' Delayed Neutrons ' by G. R. Keepin Progress in Nuclear Energy, Series I, Physics and Mathematics Vol. I, Pergamon Press

If there is an independent source of neutrons producing S neutrons per sec uniformly over the reactor, then

$$\frac{dn}{dt} = S + \frac{kn}{\tau_0}(1-c) + \sum_j \lambda_j r_j - \frac{n}{\tau_0} - l\frac{n}{\tau_0} \tag{12.32}$$

$$= (\rho - c)\, k\, \frac{n}{\tau_0} + \sum_j \lambda_j r_j + S \tag{12.33}$$

using (12.4) and 12.13).

There are, therefore, seven simultaneous differential equations to solve for n. We shall only consider the problem of a reactor running steadily until time $t = 0$ when the reactivity is instantaneously altered from $\rho = 0$ to a constant value ρ which may be positive or negative. We shall also put $S = 0$ for simplicity.

The equations (12.39) and (12.42) can be satisfied by taking a series of exponential terms

$$n = \sum_s A_s e^{\omega_s t} \tag{12.34}$$

$$r_j = \sum_s A_{sj} e^{\omega_s t} \tag{12.35}$$

Substitution of these in (12.32) and (12.33) eads to the condition

$$\frac{\omega_s \tau_0}{k} = \rho - c \sum_j \frac{\omega_s \mu_j}{\omega_s + \lambda_j} \tag{12.36}$$

This means that for a given reactor, that is given delayed neutron characteristics and k, the values of ω_s are functions of ρ, that is, k_e, only.

It can be seen from (12.36) that for any value of ρ there are seven values of ω_s, that is, s runs from 1 to 7, and ω_s can be plotted as a function of ρ. It is to be noted that for $\omega_s = -\lambda_j$ the right-hand side of (12.36) becomes infinite and so there are seven vertical asymptotes as shown in Figure 12.1. Also, for very small values of $\omega_s \to 0$, $\rho \to 0$ either positively or negatively if ρ is respectively positive or negative. Then, calling this value ω_1

$$\rho \simeq \frac{\omega_1 \tau_0}{k} \tag{12.37}$$

There is some maximum possible value of ρ for any given reactor, though it is not possible to say strictly what this is as it will depend on how the changes in ρ are brought about, but clearly it can never even approach the value $(\tau_i - 1)/\tau_i$. The other extreme limit, $k_e = 0$ or $\rho = -\infty$ would also be impossible to reach in practice.

5. The case of ρ positive

We now wish to consider the variation of n with time for ρ positive. From Figure 12.1 it is seen that there will then be six negative values of ω_s and one positive value ω_1, and so n will be composed of six negative and one positive exponential terms. Of the negative terms the one which persists the longest will be $e^{\omega_2 t}$ and $\omega_2 < \lambda_1 = \tau_1^{-1}$. Now $\tau_1 = 78{\cdot}3$ sec and so even this term will have become small after a time equal to some few multiples of 78·3 sec. So that after such a time only the positive term will remain important and we can write

$$n \to A_1 e^{\omega_1 t} \tag{12.38}$$

so that ultimately the power level rises exponentially with a relaxation time ω_1^{-1}.

For large positive values of ρ, that is large values of k_e, ω_1 will be large and so from (12.36)

$$\omega_1 \simeq k\rho/\tau_0 \tag{12.39}$$

The rise of power with time is then extremely rapid, and after the initial transient terms due to the other ω's have died out, occurs as if there were no delayed neutron present. This is seen by combining (12.39) with (12.38) to give (12.14)—the result without delayed neutrons.

There is one other point to notice about this case. The rate at which the power can be ultimately made to rise, given by (12.38) and (12.39), is limited only by the value of ρ it is possible to induce into the reactor.

6. The case of ρ negative

In this case it will be seen from Figure 12.1 all the ω's are negative. One of these ω_1 will be numerically the smallest and so will persist the longest. So again, as for ρ positive, after a time which allows $e^{\omega_2 t}$ to become negligibly small

$$n \rightarrow A_1 e^{\omega_1 t} \tag{12.40}$$

where the A_1 is not the same as in the previous case. Now as ω_1 is negative, the power ultimately dies away exponentially to zero. In this case, however, there is a limit to the rate of power decrease, as given by (12.40), which is quite fixed. This is because there is a limit to ω_1 as ρ becomes increasingly

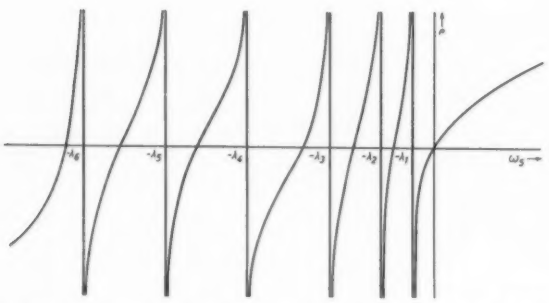


Fig 12.1 Values of ω_s as a function of reactivity ρ (not to scale)

large negatively as can be seen from Figure 12.1. For as $\rho \rightarrow -\infty$, $\omega_1 \rightarrow -\lambda_1$ and so in this case

$$n \rightarrow A_1 e^{-\lambda_1 t} \tag{12.41}$$

This means that the power, in the limit, cannot decay at a rate faster than a period of 78·3 sec.

7. The case of ρ small

For ρ small, irrespective of sign, it can be seen that the dominant ω, ω_1, is small. So from (12.36) putting ω_1 small

$$\rho \simeq \frac{\omega_1 \tau_0}{k} + c\,\omega_1 \sum_j \mu_j/\lambda_j \tag{12.42}$$

so that

$$\omega_1^{-1} \simeq \frac{1}{\rho}\left[\frac{\tau_0}{k} + c \sum_j \mu_j/\lambda\right] \tag{12.43}$$

and substituting this into (12.38)

$$n \rightarrow A_1 \exp\left(\frac{\rho t}{\dfrac{\tau_0}{k} + c \sum \mu_j/\lambda_j}\right) \tag{12.44}$$

for ρ either positive or negative.

Now, $\sum_j \mu_j/\lambda_j$ is a constant for a particular fissionable material, and using the figures given in Table 12.1

$$c \sum_j \mu_j/\lambda_j = 92{\cdot}4 \times 10^{-3} \text{ sec} \tag{12.45}$$

and so again, taking as an illustration $\tau_0 = 1{\cdot}5 \times 10^{-3}$ sec, and putting $k = 1$, as an approximation

$$\frac{\tau_0}{k} + c \sum_j \mu_j/\lambda_j = 93{\cdot}9 \times 10^{-3} \text{ sec} \tag{12.46}$$

and so (12.44) becomes, in this case

$$n \rightarrow A_1 \exp\left[\frac{\rho t \times 10^3}{93{\cdot}9}\right] \tag{12.47}$$

There are two points to note about this result. First, if it is compared with (12.25) which is the corresponding case without delayed neutrons, it is seen that after the power change has settled down to a single exponential, the rate of power increases is enormously slowed up by the presence of the delayed neutrons. The relaxation times in the two cases are in the ratio of $93{\cdot}9/1{\cdot}5 = 63$. Secondly, it is seen from (12.46) that the term τ_0/k is small compared with the other term, which depends only on the delayed neutron characteristics. In other words the ultimate power increase or decrease as given by (12.47) is almost independent of the reactor for small values of ρ.

It should be appreciated that this approximation for ρ small requires that ω_1 is very much less than λ_1. In terms of the relaxation time $T_1 = |\,\omega_1^{-1}\,|$ this means that $T_1 \gg 78{\cdot}3$ sec. Then for, say, $T_1 \simeq 1000$ sec, the value of ρ given by (12.43) will be correct to about 1 per cent. In this case for $T_1 = 1000$ sec, using (12.46), $\rho = 9{\cdot}39 \times 10^{-6}$.

8. Reactor kinetics with one group of delayed neutrons

Many problems in reactor kinetics can be illustrated by the use of only one group of delayed neutrons. An 'average group' is taken which has a mean lifetime τ obtained by taking the average value for all the groups, so that

$$\tau = \sum_j \mu_j \tau_j \tag{12.48}$$

and for the particular values in Table 12.1 this gives

$$\tau = 12{\cdot}4 \text{ sec.} \tag{12.49}$$

We again take $c = 0{\cdot}00703$.

For this case (12.36) reduces to a quadratic equation

$$\rho = \frac{\omega_s \tau_0}{k} + \frac{c}{\omega_s + \lambda} \tag{12.50}$$

where $\lambda = \tau^{-1}$ and there are two values ω_1 and ω_2. Simple expressions can be found for ω_1 and ω_2 if $\rho \ll 1$ and $\tau_0/\tau \ll c - \rho$. If we again take $\tau_0 = 1{\cdot}5 \times 10^{-3}$ sec, then $\tau_0/\tau = 1{\cdot}2 \times 10^{-4}$ so the second approximation is a reason-

able one. Under these conditions

$$\omega_1 \simeq \rho/(c-\rho)\tau \qquad (12.51)$$

and

$$\omega_2 \simeq -k(c-\rho)/\tau_0 \qquad (12.52)$$

and for the initial conditions that $n = n_0$ and $dr/dt = 0$ at $t = 0$, then

$$\frac{n}{n_0} = \frac{c}{c-\rho} exp\left[\frac{\rho t}{(c-\rho)\tau}\right] - \frac{\rho}{c-\rho} exp\left[-k(c-\rho)\frac{t}{\tau_0}\right] \qquad (12.53)$$

If ρ is positive, and because it is small and so less than c, $\rho/(c-\rho)$ is positive, and so n is made up of the difference between two exponential terms, the first one increasing and the second decreasing. Again, ω_2 is very much greater numerically than ω_1, the negative exponential term decays quickly compared to the increase in the positive exponential term. So n/n_0 is made up for ρ positive, of an increasing exponential term with a transient negative exponential term, so that after a time long compared with ω_2^{-1}, we can write

$$\frac{n}{n_0} \simeq \frac{c}{c-\rho} exp\left[\frac{\rho t}{(c-\rho)\tau}\right] \qquad (12.54)$$

so that the reactor period T_1 is $(c-\rho)\tau/\rho$. Equation (12.53) is illustrated in Figure 12.2.

It can readily be seen from (12.53) that the initial rise of n is very steep, in fact, almost as if the delayed neutrons were not present. This is as would be expected, because before $t = 0$ it has been assumed that the reactor was running steadily. Then a sudden change is made in ρ which immediately produces a response in n, but because the average delayed neutron lifetime is 12·4 sec, it will be an appreciable time before there is a change in the rate of production of the delayed neutrons. From (12.54) at $t = 0$

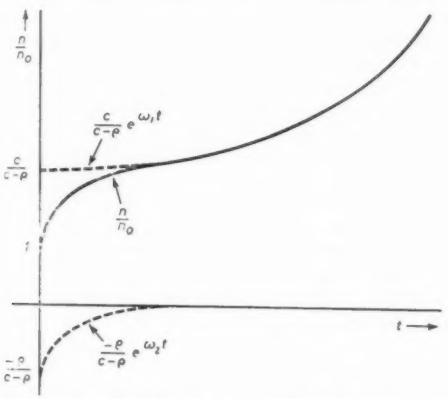


Fig 12.2 Growth of number of neutrons with time assuming one group of delayed neutrons

$$\frac{1}{n_0}\frac{dn}{dt} = \frac{c\rho}{(c-\rho)^2\tau} + \frac{k\rho}{\tau_0} \qquad (12.55)$$

and again from our approximations, the first term is small compared with the second and so

$$\frac{1}{n_0}\frac{dn}{dt} \simeq k\rho/\tau_0 \qquad (12.56)$$

which is the same as (12.11)—the case without delayed neutrons.

If ρ is negative, then both ω_1 and ω_2 are negative, but in this case ρ is negative and so the exponential terms are added. Again the second term soon becomes small compared with the first as illustrated in Figure 12.3.

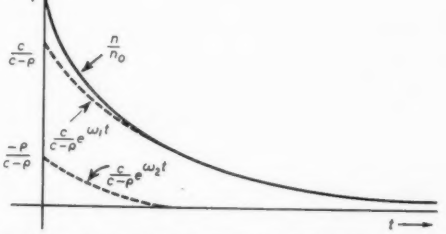


Fig 12.3 Decay of number of neutrons with time assuming one group of delayed neutrons

For the same numerical value of ρ it can be seen from (12.54) which applies irrespective of the sign of ρ, that the effect of the delayed neutrons on the rate of change of n is greater for ρ negative than ρ positive because $c/(c-\rho)$ is numerically larger when ρ is negative than when ρ is positive. This means that after the transient term has become unimportant, the value of n for a positive ρ will have increased more than the value of n will have decreased for the same negative ρ.

This instalment is the last in the present series which formed a basic course in reactor physics for engineers and designers.

LETTERS

SIR,

Why is it that NUCLEAR POWER continues to use the American word 'fissionable' when most British writers use the shorter and more descriptive 'fissile'?

The *Concise Oxford Dictionary* does not record the longer word and defines 'fissile' as:

fissile, a. cleavable, tending to split. Hence **fissility** n. [f.L *fissilis* (FISSURE,-IL.)]

Webster (1946 ed) ignores 'fissionable' and gives:

fissile *adj.* [L. *fissilis,* fr. *fissus,* past part. of *findere* to split] Capable of being split, cleft or divided in the direction of the grain, like wood, or along natural planes of cleavage, like crystals.

These definitions seem to me adequate to describe the property of certain substances to undergo the process of nuclear fission. Furthermore, the term is widely used in the biological sciences and indeed was borrowed from there in the first place.

Yours etc

Birmingham J. B. MORRIS

Perhaps most British writers still do use 'fissile' but more are changing to the other form. We preferred it partly for this reason and partly because it seems a better description of the process. The fact that the biologists use the word 'fissile' does not necessarily make it suitable for our purpose—ED.

BOOKS

Progress in Nuclear Energy: Series V Metallurgy and Fuels Vol 1 Ed. H. M. Finniston and J. P. Howe. 9 in. by 6 in. 805 + viii pp London 1956: Pergamon Press 147s

This is the first volume of a number to be produced on Metallurgy and Fuels, a subject which forms Series V of a group of books being published under the heading of Progress in Nuclear Energy. The subject is one on which there has been great secrecy during the development of nuclear energy and on which there was no great release of information until the Geneva Conference in 1955. There is therefore much ground to be covered and the accumulated results of more than ten years of intense research activity are presented to the reader in this volume. The task of the editors and of the authors has been enormous and the results of their efforts is an encyclopædic volume of information which all in the nuclear energy field must have at hand for constant reference.

Although the work is encyclopædic in proportions and in coverage it is nevertheless extremely readable and will be found equally acceptable to the student, the expert and the metallurgist or physicist who wishes to glean some information about this new branch of his subject.

The material is presented under nine main headings and there are thirty-two papers distributed among these. The headings are :

1. The production and preparation of uranium metal
2. Thorium
3. Beryllium and zirconium
4. The physical metallurgy of plutonium
5. The preparation and properties of the rare earths
6. Ceramics
7. Fuel elements
8. The effects of radiation
9. Solid state physics

The papers are all written by leading authorities and the writing and presentation are of a high order and bear the signs of careful preparation and editing.

Bearing in mind the general high quality of the contributions it would be pedantic in a short review of a book of 800 pages to attempt detailed criticism and the present writer does not intend to do so. It is more appropriate to welcome the publication of this mass of information and to reflect, with Dr Cyril Smith, in his foreword, that ' the opportunity, even the duty, of scientists and engineers to publish is the best way of ensuring adequately high standards '.

The book is well produced and clearly printed and, as far as the reviewer has been able to determine, the index is full and has been carefully prepared. The big disadvantage of this book is its price of £7 7s. 0d. This is a pity because it is likely to restrict purchase by individuals—and it is a book which should find a place on the personal shelves of many physicists, metallurgists and engineers.

J. G. Ball

An Approach to Modern Physics E. N. da C. Andrade. 8·5 in. by 5·5 in. 228 pp London 1956: G. Bell and Sons Ltd. 25s.

Andrade's *Mechanism of Nature* was first published in 1930 and last revised in 1936. It has now been considerably extended and almost completely rewritten to cover the revolutionary developments of the last twenty years, and given a different and more appropriate title. The result is a very readable book for the intelligent layman who wants to add to the science he learnt at school, written by a man who has played no mean part in shaping the present state of physical knowledge.

Among the subjects now covered are cosmic rays, ultrasonics, radio astronomy, and electron microscopy. A new final chapter on uncertainty approaches this sometimes abstruse subject simply and from a philosophical standpoint. The chapters on atomic and nuclear structure have been brought up to date, and another chapter deals with atomic energy. Although the publication date of the book was February 1956, Andrade writes of large scale nuclear power production as a future development (' the large scale nuclear reactor may have a great future as a generator of heat for power production ')—so fast has this field developed.

Although in a book of this scope and length the topics must necessarily be dealt with briefly, relativity theory is conspicuously absent from its pages except in brief mentions in spite of the fact that the Michelson-Morley experiment is described comparatively fully. This is a conspicuous omission in an otherwise comprehensive book.

The historical approach often adopted is a useful one. Analogies employed are usually pertinent and realistic—for instance, ' heavy water is expensive, costing about thirty-five times as much as whisky '. The book is illustrated with line drawings and photographs, and it is notable that it does not contain a single mathematical formula.

P.A.M.

Atomic structure and the strength of metals N. F. Mott. 5 in. by 7½ in. 64 pp. London 1956: Pergamon Press Price 15s.

In these days when nuclear power, electronics and automation steal the popular headlines, it is timely that we should be reminded of the importance of one of the foundations of this advanced technology—the science of metals. Indeed, as Professor Mott demonstrates in these short non-technical lectures delivered before an audience of American arts undergraduates, metallurgy has played an essential part from the earliest times in the development of civilization. Its very antiquity has resulted in the accumulation of a tremendous volume of practical knowledge and it is a curious paradox that it is only within the last twenty-five years that a coherent theory has emerged to explain many of the puzzling phenomena of metal deformation. The lectures comprise a simple and admirably clear explanation of the mechanism of plastic deformation, hardening and crystal growth in terms of the movement and interaction of dislocations and other crystal lattice defects. The book is well illustrated with photographs and line diagrams which help to concretize the difficult dislocation concept.

Most reviewers have long since given up regretting the impossible price of books. This one certainly deserves a wider sale than it is likely to get. One can only express a pious hope for a cheap edition soon.

J. W. Menter

Atomic Weapons and East-West Relations P. M. S. Blackett 5 in. by 7·5 in. 107 pp London 1956: Cambridge University Press Price 8s 6d

It was an unusual move on the part of Trinity College, Cambridge, to invite a physicist to give the Lees Knowles lectures on military science; but then Professor P. M. S. Blackett is an unusual physicist. His experience of military matters stretches from a brief naval career during the first world war to high-level planning of antisubmarine warfare in the second. In between he made his name as one of Rutherford's most notable disciples in those exciting days when atom splitting was new; to this he added very important work on cosmic rays and rock magnetism. But even in physics it was his sense of strategy which brought him success; his ability to look ahead and to judge the best means of reaching his goal.

The book before us contains those three lectures, concerned with the effect of Nuclear Weapons on strategic thinking, which

Blackett gave in Cambridge in the spring of 1956. Here is no armchair strategist offering facile solutions to the terrible threat of atomic weapons; nor, on the other hand, is he tempted into emotionalism. The book, coolly and critically written, with a few touches of sarcastic humour, is based on thorough knowledge of a large number of documents ranging from newspaper reports to politicians' memoirs. It is not possible to summarize the author's conclusions in a short space. Indeed he does not reach the conclusion that this or that course of action will cure all evils and solve all problems. Instead he presents us with a careful analysis of the various sets of opinion and judgment which have shaped the changing course of atomic policy all over the world. In my view, no one interested in world politics can afford to miss this intelligent and readable little volume.

O. R. Frisch

The New World of the Atom James Stokley, 6 in. by 8½ in. 288 pp New York 1957: Ives Washburn, 53 Fifth Avenue Price $5·50

And What of Tommorow George O. Robinson, 5½ in. by 8½ in. 178 pp New York 1956: Comet Press Books, 11 West 42nd St Price $3·00

The story of the dramatic events in the Chicago squash court on December 2, 1942, has now been pressed into an official legend and no variations seem to be allowed. How Fermi's first chain-reacting pile first became critical is duly repeated in both these books down to the finest detail (Fermi's 'broad smile', Wigner's chianti, the paper cups, the natives-were-friendly phone call etc etc). Of course neither of these authors were present, but 42 people were and it would be refreshing to find out how some of them felt about it all.

The authors of these two latest additions to an already vast corpus of atomic background for the layman are both journalists and write easily enough. Mr Robinson does not attempt very much in 'explaining' atomic energy and concentrates rather on people ('Dr Kistiakowski threw his arms around Dr Oppenheimer and embraced him with shouts of glee') and statistics ('37,562,000 board feet of lumber used in building the electromagnetic plant'). His people however remain mere names and the statistics are generally of the kind quoted. As far as Britain's contribution to nuclear energy is concerned, the only mentions are—Nunn May and Klaus Fuchs.

Mr Stokley's book is a very different affair. His descriptions of the technicalities are adequate and should satisfy the layman without seriously enraging the physicist. He is probably at his best in his section on the impact of Atomic Energy. Britain's contribution both to the bomb and to subsequent developments is very fairly treated and Calder Hall is described at some length (albeit not too accurately).

By the way, why is it that so many authors (and not only Americans) simply cannot spell Sir John Cockcroft's name?

W.D.

Television Explained 6th Edn. W. E. Miller (revised by E. A. W. Spreadbury) 5½ in. by 8¾ in. 184 + xi pp. London 1957: Iliffe

The design of television receivers has undergone some changes in the past few years. This has been mainly due to the introduction of the alternative television programme in this country and the consequent necessity for aerial and receiver designs which allow easy change-over from one transmission to the other. This involves the use of switched turning and automatic gain control, and increased use of flywheel synchronization and dual aerial systems. In the new edition of this well-known book which has been prepared by E. A. W. Spreadbury all these new features, as well as those of the older receivers are included.

The book assumes a knowledge on the part of the reader of ordinary sound radio receivers and provides in simple terms an explanation of the operation of television circuits as used in present day receivers. The book is written primarily for radio service engineers, but should be of value to all who wish to understand the operation of a television receiver.

Denis Taylor

Radioéléments Artificiels Liste No 4—March 1957. Commissariat à l'Energie Atomique, Service des Radioéléments Artificiels, Boîte Postale No 2, Gif-sur-Yvette, Seine-et-Oise, France

Hard on Harwell's 4th edition of their Isotope Catalogue (reviewed in NP March 1957) comes the latest French list. The two catalogues are very similar, the main difference—apart from the language of course—being the spirax binding for the French one. The range of French products has been extended —for example Ce-137 from fission products will be available later this year—and there are minor changes in the tariff.

PUBLICATIONS

Marconi Instrumentation March 1957 contains articles on measurement of VHF, UHF and audio frequency power: Marconi Instruments Ltd, St. Albans.

M.A.C. (Morgan automatic computer) by A. F. Watson BSc. AInstP. A 129-page book describing the principles and operation of the Hollerith HEC 4 computer installed at Morgan Crucible Co Ltd, Battersea Church Rd, London, SW11.

Lafarge Aluminous Cement Co Ltd, 73 Brook St, London, W1, have issued a booklet on their high-purity, white calcium-aluminate cement—*Secar* 250. This is suitable for temperatures between 1200 and 1800°C which is beyond the range normally covered by Ciment Fondu refractory concrete.

BSI Yearbook 1957 On Jan 1, 1957, about 3000 British Standards and Codes of Practice were current. These are listed in 400 pages of the 480-page book. Price 15s. (plus 1/6 postage) from: British Standards Institution, 2 Park St, London, W1.

Bowthorpe Electric Co Ltd, Tinsley Lane, Crawley, Sussex, have published a catalogue (BH 50) of their fittings for overhead lines, including line taps and shrouds.

Venner Electronics Ltd, New Malden, Surrey, have issued a catalogue (publication VE 104) dealing with their range of transistorized plug-in units for industrial units such as oscillators, amplifiers, counting and scaling units etc. These units are extremely small and weigh only ounces.

The Nucleus No 12 gives some details of the solution type reactor recently installed at the Armour Research Foundation in Chicago. Nuclear Instrument and Chemical Corporation, 231 West Eric St, Chicago, Ill.

Lion Electronic Developments Ltd, Hanworth Trading Estate, Feltham, Mddx, have published a brochure describing their service for development and production of resin castings and resin-encapsulated electronic circuits and components.

Cintel Synopsis A general catalogue describing in outline the main products of Cinema-Television Ltd, Worsley Bridge Rd, London, SE26.

Hilger Journal February 1957 includes an article by Dr J. J. Kipping, *The use of the Rayleigh interferometer with volatile liquids* and one by Mr I. G. Morgan, *An introduction to microwave spectrometry*.

'Friendly anxiety'—Chandos

The CEA stations at Bradwell and Berkeley were both referred to last month by the respective chairmen of the main contracting groups. Presenting his annual report to the AEI shareholders, Lord Chandos said Sir Claude Gibb, the Nuclear Power Plant Co's chairman, was an old friend and he had a lively admiration for his work during the war when he (Lord Chandos) was Minister of Production. The AEI chairman said he would be watching the progress of the two stations with a jealous but friendly anxiety. He said AEI were determined to make Berkeley the first station to come into production.

Referring to the AEI research station at Aldermaston, Lord Chandos said it had been engaged on fundamental research since 1946 and he paid tribute to the research chief, Dr T. E. Allibone FRS, to whose efforts a notable part of AEI's success must be attributed. He confirmed that Aldermaston were at present working on thermonuclear fusion which he referred to as a 'challenging problem'.

He also praised Mr Harry West, managing director of the AEI-JT Nuclear Energy Co and Mr S. A. Ghalib and his staff of engineers who were responsible for the detailed design of the Berkeley station.

Sir Claude Gibb's address was to the shareholders of A. Reyrolle & Co Ltd—one of the Nuclear Power Plant Co Group. He recalled that last year he had announced that Reyrolle would supply control gear for reactors in addition to standard main and auxiliary switchgear: he could now state that Reyrolle would assist in the manufacture of moderator graphite in the Anglo Great Lakes Corporation Ltd, construction of whose new factory on Tyneside had already begun.

5MeV accelerator for radiography

Believed to be the first of its kind ever supplied for industrial radiography, a 5MeV linear accelerator has recently been installed at a Ministry of Supply establishment. The machine was designed and built by Mullard Research Laboratories on behalf of the contractors, Philips Electrical Ltd. The accelerator has been designed to give extremely good definition and despite the high energy and large output of 500 röntgens a minute at 1 metre, the electron beam which creates the X-rays has a diameter of only 2mm at the target. A special magnetic focusing device is associated with the X-ray lead.

The machine is mounted on a travelling gantry and can be tilted so that it can be brought conveniently to the specimen. A radiograph of very high definition can be obtained in steel 9 or 10 inches thick with only half-an-hour's exposure.

Bradwell Goliath ordered

In order to carry out some of the very large lifts required in building the Nuclear Power Plant Co's Bradwell power station, orders have been placed for special lifting equipment with Clyde Crane & Booth Ltd. This was mentioned by Mr J. B. Woodeson, chairman of Clarke, Chapman & Co Ltd, at his company's 64th annual general meeting held in Gateshead on April 4. Clyde Crane & Booth Ltd are associated with Clarke, Chapman, and one of their orders is for a Goliath crane which will be one of the largest of its kind ever made in this country. It will have a span of 165ft and a height of 160ft to the hook and is designed to lift 200 tons.

Mr Woodeson said his firm's share of the Bradwell contract—steam raising equipment (in association with Head, Wrightson Ltd), a large part of the erection work, plant services at the site during construction—constitutes a significant proportion of the overall value of the contract.

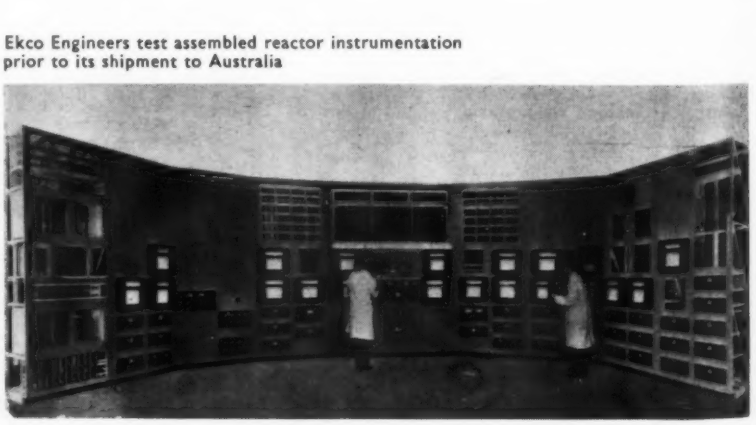
Australian DIDO instrumentation

Ekco Electronics Ltd are to supply the complete nucleonic instrumentation and control circuitry for the first experimental atomic reactor to be exported by the UK. This is the heavy water, enriched uranium DIDO type reactor now under construction at Lucas Heights, near Sydney, for the Australian Atomic Energy Commission. The instrumentation has been pre-tested at Ekco's Southend works and is shortly to be shipped to Australia. Under contract to Head Wrightson Processes Ltd, Ekco engineers will also be responsible for the erection, testing, installation, and commissioning of the entire nucleonic instrumentation on site in Sydney. With a thermal output of 10 MW and a flux of 10^{14} the Australian DIDO will provide extensive experimental facilities and will enable essential research to be performed in a shorter time than previously.

The monitoring, control and safety instrumentation is contained in a series of instrument panels grouped around the control position. One group of instruments measures and records the physical states of the reactor circuits such as pressure, flow and temperature of the heavy water. A second group measures the neutron flux at various points in the reactor as well as the rate of change of flux and its departure from a predetermined level. Information from both the physical and nuclear instrumentation is combined with indications of reactor conditions and fed to a system which ensures the safe operation of the reactor at all times. In-built control circuits ensure that a definite procedure sequence is followed when starting up the reactor. Failure to carry out this sequence prevents the reactor from becoming operational. Automatic fault-detection and graded shut-down are incorporated.

Health instrumentation is provided at numerous points in and around the reactor to monitor both the gamma and the fast neutron dose-rates. In the case of gamma radiation the reading is displayed both locally and remotely on logarithmically scaled meters and is also recorded.

Ekco Engineers test assembled reactor instrumentation prior to its shipment to Australia



150-lines-per-minute printer installed at AWRE, Aldermaston, with 4 magnetic tape units in background. Middle right is the card punch

IBM 704 computer for AEA

IBM United Kingdom Limited recently supplied an IBM 704 computer to a UKAEA establishment. The machine was delivered to its specially prepared, air-conditioned building in mid-January and went to work about three weeks later.

In addition to the central processing unit and the storage devices, the installation consists of a card reader for input; a card punch and a 150-lines-per-minute printer for output. A cathode ray tube output device is also being added; this will show the result of calculations in the form of a graph which can be photographed as a permanent record.

Storage consists of two high-speed core storage units, each with a capacity of 4,096 computer words (36 binary digits per word) and an access time of 12 microseconds, and two magnetic drum units, each of which consists of four addressable magnetic drums and provides an additional storage capacity of 8,192 full words. In addition, there are ten magnetic tape units, each of which can read or write at the rate of 15,000 characters per second. When punched cards are used, some 6,000 numbers per minute can be fed into the card reader and the machine can execute most of its instructions at the rate of over 40,000 a second. This means that in 22 seconds the computer can solve 30 simultaneous equations involving 54,000 multiplications and the same number of additions.

Over 300 of the IBM 700-series machines have been ordered or installed in the United States for research on basic science.

AEA pipe contract for Mitchell

A contract for pipework installation at the UKAEA Springfields works was recently awarded to Mitchell Engineering Ltd. Work in this contract falls into several stages, the value of the first being estimated at several thousand pounds. This contract is the fifth to be awarded to Mitchell companies by the AEA for civil engineering and pipework on atomic projects. The Mitchell Construction Company is at present carrying out the civil construction at the AEA's power/plutonium station at Chapel Cross and the erection of six cooling towers at Capenhurst gaseous diffusion plant where the parent company, Mitchell Engineering Ltd, is installing pipework. The fourth contract is for pipework installations at Dounreay.

Adamson's get ready

Plans were announced last month for a 30,000 ft² extension to the Dukinfield, Cheshire, works of Daniel Adamson & Co Ltd. This will provide additional engineering capacity for the Fabrication Department which is increasingly concerned with production plant for the nuclear energy field.

As reported in NP (Worldview March), Adamson's have concluded an agreement with Alco Products Inc, Schenectady, NY, and Humphreys and Glasgow Ltd of London to build Alco-designed pressurized water power reactors of between two and 20 MW capacity. Recently officials of Adamson's were in the United States ascertaining the special facilities needed for manufacturing components for the Alco reactors and other equipment. Facilities in the new extensions, which it is hoped to have operating by the end of the year, are expected to be the first in Britain capable of producing plant for pressurized water reactor systems.

The company at present employs 1,200 workers. The expansion programme will probably provide work for about 250 more men—mainly platers, welders and fitters.

Zircaloy tank welded

A large Zircaloy-2 core vessel for an experimental homogeneous nuclear power reactor was recently completed in the United States at the Newport News Shipbuilding & Drydock Company. Zircaloy-2 sheets, $\frac{1}{8}$ to $\frac{3}{4}$in. thick, were pressed into the required conical and spherical shapes for the main body of the tank, and machined forgings were used for the inlet and outlet pipes. The assembly work consisted in welding the sections to each other and fitting the inlet and outlet pipes.

Zirconium and zirconium-rich alloys react readily with nitrogen, carbon, and oxygen, to form brittle compounds and solid solutions in the weld area. Complete shielding of the welds is necessary, and, the *Heliarc* welding method, which uses a helium gas shield, was chosen. First, an insert wire of Zircaloy-2 was manually tack-welded in the joints. Then the joints were fusion-welded mechanically using swaged Zircaloy-2 filler wire and a water-cooled shielding apparatus especially designed to conform with the shapes of the welded surfaces. The reverse sides of the welds were also shielded by helium gas to the weld area. In the conical sections, the ends of the assembly were plugged and the enclosed area flooded with helium gas.

The most complex sub-assembly involved the welding of perforated Zircaloy-2 discs cross-sectionally inside the 30 and 90 degree sections of the main body. These screens, which facilitate uniform flow of the liquid fuel through the tank, were manually welded with a *Heliarc HW-9* torch. All welds were examined by radiographic and ultrasonic methods.

In Brief

Heat Transfer Ltd, 30 Church St, Croydon, announce the appointment of two new agents for all their types of heat exchanger equipment, condensers etc.

W. P. B. Coleman Ltd, 29 Oxford St, Newcastle on Tyne—agents for the North East Coast.

McCulloch & Miller, 180 West Regent St, Glasgow C2—agents for Glasgow and environs.

NAMES IN THE NEWS

Vickers Ltd announce that as from September 1, 1957, **Mr C. L. Old,** BSc, MSc, MICE, MIMechE, AFRAeS, MIPE, Principal of the Wolverhampton College of Technology has been appointed Group Education Officer. He will be responsible primarily for the coordination of all education and training activities in the Vickers Group Companies.

Mr P. C. Walker has been appointed liaison officer for the British Atomic News film campaign. The scheme is intended for the promotion abroad of British nuclear energy products, and the first production will have its premier this month.

Mr K. G. Sinclair has been appointed chairman of Griffin & George Ltd, the laboratory furnishers.

Mr Harry L. Browne has joined General Dynamics Corporation's Atomic Division as an assistant to the division general manager. Mr Browne was previously manager of the nuclear products department of Thompson Products Inc. and in the years 1947 to 1955 was an engineer and administrator with the United States Atomic Energy Commission and the Manhattan District Project.

Mr Austin Kelly, naval architect to Vickers-Armstrongs (Shipbuilders) Ltd has retired.

Mr F. H. Roberts has been appointed a director and chief engineer of John Thompson (Australia) Pty Ltd, a member company of the John Thompson Group. Mr Roberts has played an important part in the development of power station plant in Victoria, Australia, and has written numerous engineering papers.

Expandite Ltd have appointed **Mr D. M. Price,** ACIS, secretary/accountant to their susbidiary company Expandite (South Africa) (Pty) Ltd, Johannesburg. **Mr R. E. Harris,** formerly resident sales manager, has been appointed a director.

Mr S. A. Clodd, works manager, Radio and Television, E. K. Cole Ltd has been appointed an executive director of the company. He joined Ekco in 1941 as material controller.

Mr L. C. Harman, divisional administration executive of Smiths Aircraft Instruments Ltd has been appointed to the board of Waymouth Gauges and Instruments Ltd as financial director.

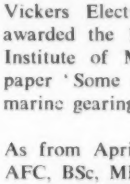
Mr L. H. E. Jones, overseas technical representative of Expandite Ltd, leaves London on May 5 for an extensive tour of the Near and Far East.

The CEA have appointed **Mr P. Briggs,** at present deputy controller of the North West, Merseyside and North Wales Generating Division, to be controller of the Yorkshire Division in succession to **Mr G. A. Vowles** who has retired.

Following the recent death of **Mr H. W. P. Matthey, Mr G. C. H. Matthey,** joint managing director for 35 years has been elected chairman of Johnson, Matthey & Co Ltd.

Dr W. H. Darlington of Metropolitan-Vickers Electrical Co Ltd has been awarded the 1956 Silver Medal of the Institute of Marine Engineers for his paper 'Some considerations of wear in marine gearing'.

As from April, **Mr J. A. Smale,** CBE, AFC, BSc, MIEE, formerly engineer-in-chief of Cable and Wireless Ltd became technical consultant in Telecommunications Engineering to Marconi's Wireless Telegraph Co Ltd.



The CEA announce the retirement of **Mr F. Shakeshaft,** OBE, AMIEE, MInstF, who as mechanical engineering consultant to the Authority, was concerned with future design and generation problems.

INSTITUTIONS

Atom theme for safety show

The fourth Safety and Factory Efficiency Exhibition opening at Bingley Hall, Birmingham, on June 14, will have an atomic energy emphasis. A wide range of safety equipment, protective clothing, health and welfare products and services, and material handling equipment will be on show. The UKAEA will stage a large exhibit called *Atom 1957* giving a comprehensive picture of atomic energy as it is today and its probable future. It will include a working model of Calder Hall, and a colour film with animated diagrams will describe its principle of operation. Sections of the stand will illustrate the uses of radioisotopes in research, medicine, agriculture and industry, and methods of protection against radiation hazards. A week-end study congress will be held in conjunction with the exhibition at which the chairman will be Dr P. F. R. Venables, principal of the Birmingham College of Technology. Four papers will be given: *Training for atomics* by Mr Ivor Hopkins, UKAEA; *Isotopes in industry* by Dr H. Seligman, AERE; *Health and safety when using radioactive materials* by Dr A. S. McLean, and *Atomic reactors* by Dr J. V. Dunworth.

Charter for Chemicals

The Institution of Chemical Engineers has received a Royal Charter from the Queen. A communication to this effect was received by the Institution from the Privy Council Office on February 22. The grant of a Charter was the result of a Petition signed by the President, Mr John A. Oriel and a group of members, including Sir Christopher Hinton.

The Institution of Chemical Engineers was founded in 1922 and now has a membership of 3500.

US talks on liquid scintillators

Northwestern University, Evanston, Illinois, is to hold a conference on *Liquid Scintillation Counting* at the Technological Institute from August 20 to 22. A wide range of topics on the theory and application of liquid scintillators is covered by invited papers: coincidence counters, single channel counters, chemistry of liquid scintillators, and applications in biology and medicine, industry, archaeology, physics, chemistry and engineering. Abstracts of non-solicited papers should be sent to the Pro-

gramme Chairman, Dr F. Newton Hayes, Los Alamos, New Mexico, by June 1, 1957.

Hydrazine and Water Treatment

A conference on this subject, organized by Whiffen & Sons Ltd, will take place in Bournemouth from May 15–17. Hydrazine solution, marketed by Whiffen under the trade name of *Zerox* is continuously injected into boiler feed waters in small quantites and acts as a deoxygenator. This is important in corrosion prevention, especially in high-pressure boilers, and has obvious applications in nuclear power stations as well as the conventional type. One of the papers at the conference, which will be presented by Dr T. A. Hall of the UKAEA, is called 'What sort of reactor ?'. The conference is academic in character and papers will be presented by visitors from America and Europe, together with reports of original research carried out on behalf of Whiffen by Birmingham University.

British Council Courses

The following two courses will take place in the autumn :

Course 728—Radioactive Isotopes in Medicine September 15–28. The first week will be spent in Sheffield at the National Centre for Radiotherapy under the Director of the Centre, George W. Blomfield, MA, FRCS. The second part of the course will be held at the University of London Post-graduate Medical School and also at University College Hospital Medical School. The Director of Studies here will be Dr W. Russell Fraser, MD, FRCP. The course is open to 15 overseas qualified medical practitioners.

Course 720—Digital Computers October 27–November 9 Lectures will be held in London and visits arranged to various computing establishments. Director of studies will be Dr Andrew Booth, Birkbeck College. A knowledge of basic principles will be assumed. Full details of these courses can be obtained from British Council, 65 Davies St, London W1.

RESEARCH REPORTS

United Kingdom

*The following reports have been made available to the public by the United Kingdom Atomic Energy Authority. They may be borrowed or photocopies obtained from the Science Library, London, Department of Industrial and Forensic Science, Belfast, the Mitchell Library, Glasgow, and the Central Libraries at Acton, Birmingham, Bristol, Kingston-upon-Hull, Leeds, Liverpool, Manchester, Newcastle-upon-Tyne and Sheffield. They are also deposited in the Copyright Libraries (i.e. British Museum; University Library, Cambridge; Radcliffe Science Library, Oxford; National Library of Scotland, Edinburgh; National Library of Wales, Aberystwyth) and in the Patent Office Library. Reports marked * may be purchased from Her Majesty's Stationery Office.*

Reports are also available in the United States, from the USAEC depository libraries, a list of which will be found in NUCLEAR SCIENCE ABSTRACTS. Reports for sale may be purchased in the United States from: Sales Section, British Information Services, 30 Rockefeller Plaza, New York 20, N.Y.

AERE Harwell

The diffusion theory of water moderated reactor assemblies. D. A. Newmarch. (Dec 10, 1956. 21 pp) AERE RP/R 2013. 3s. 3d*

Linear dynamics in spiral ridge cyclotron design. *W. Walkinshaw, N. M. King.* (Oct, 1956. 44 pp) AERE GP/R 2050. 6s*

An investigation of the urinary excretion of endogenous creatinine from a group of male human subjects. *B. W. Oakley.* (Nov, 1956. 11 pp) AERE Med/R 2098

The effect of removing plate fuel elements upon the thermal neutron fine structure in reactor assemblies. Part 2. *D. A. Newmarch.* (Dec 10, 1956. 13 pp) AERE R/R 2112

Radiostrontium and radiocaesium measurement in biological materials to December, 1956. *D. V. Booker, F. J. Bryant, A. C. Chamberlain, A. Morgan, G. S. Spicer.* (1957. 11 pp) AERE HP/R 2182

Thorium nitrate solution as a breeder blanket in the HAR. Part 1. Thermal stability. *P. G. Jones, R. G. Sowden.* (Dec, 1956. 8 pp) AERE C/M 298

The activation resonance integral of bismuth. *P. N. Cooper.* (Nov, 1956. 12 pp) AERE R/M 93

Electromagnetic pumps and flowmeters. A bibliography of literature references and readily available reports. *M. Greenhill, C. S. Sabel.* (Oct, 1956. 9 pp) AERE Inf/Bib. 93 4th ed. 1s 9d*

Industrial Group

Determination of thermal efficiency of steam power plant. *K. J. Durrands, D. L. Linning.* (March, 1957. 14 pp) IGE-R 33

The determination of the excretion time of a urine sample using creatinine content as index. (Feb 19, 1957. 3 pp) IGO-AM/W 69

The determination of radioruthenium in seaweed ash. (Feb 8, 1957. 5 pp) IGO-AM/W 70

The determination of moisture in gaseous carbon dioxide under pressure (absorption in anhydrone). (Feb 14, 1957. 3 pp) IGO-AM/W 76

The determination of trace amounts of oil in carbon dioxide by absorption in carbon tetrachloride and infra-red spectrometry. (Mar 7, 1957. 3 pp) IGO-AM/W 78

The determination of alpha-activity due to uranium in human urine. (Feb 28, 1957. 6 pp) IGO-AM/CA 79

The niobium-hydrogen system. *D. R. Knowles* (Mar, 1957. 32 pp) IGR-R/C 190

PROGRAMME

ICE Institution of Civil Engineers. IMechE Institution of Mechanical Engineers. IEE Institution of Electrical Engineers. IChemE Institution of Chemical Engineers. IP Institute of Physics. PS Physical Society. SCI Society of Chemical Industry. IM Institute of Metals. IMet Institution of Metallurgists. IMM Institution of Mining and Metallurgy. IPE Incorporated Plant Engineers. SIT Society of Instrument Technology.

MAY

TUESDAY 7
LONDON IPE Contemporary plant engineering in the USA *H. M. Sylvester,* Office of Assistant Secretary of Defence, Washington. 7.00 at the Royal Society of Arts, John Adam St, WC2

WEDNESDAY 8
LONDON BEAMA Education conference

THURSDAY 9
GLASGOW IPE Developments in boiler feedwater treatment *J. S. Couper* 7.15 at Scottish Building Centre, 425 Sauchiehall St
LIVERPOOL IPE Nuclear reactors for power generation *J. A. Dixon* 7.15 at the Exchange Hotel

TUESDAY 14
MANCHESTER IPE High pressure hydraulic pumps and their associated control valves *A. M. Worswick* 7.15 at the Engineers' Club, Albert Square

WEDNESDAY 15
LONDON IEE A survey of transistor circuit techniques. 5.30 at the Institution

THURSDAY 23
LONDON IEE AGM followed at 6.30 by General Applications of Digital Computers *Dr A. D. Booth* At the Institution

TUESDAY 28, WEDNESDAY 29
LONDON ICE Symposium: The scaling up of chemical plant and processes. Held jointly with SCI, Het Koninklijk Instituut van Ingenieurs and De Koninklijke Nederlandse Chemische Vereniging

PATENTS

766,677 Improvements in or relating to semi-conductor materials. Standard Telephones and Cables Ltd (inventor: J. S. Blakemore) Appn: April 14, 1952. Pubd: Jan 23, 1957

The inventor has found that alloys formed from mixtures between certain intermetallic compounds can have energy gaps, and hence optical absorption edges, intermediate between those of compounds from which they have been formed and have values which bear a simple relation to the relative proportions of the compounds. The invention describes a semi-conductor material of a ternary alloy containing substantially fifty atom per cent of antimony and the remainder made up of two elements chosen from indium, gallium and aluminium.

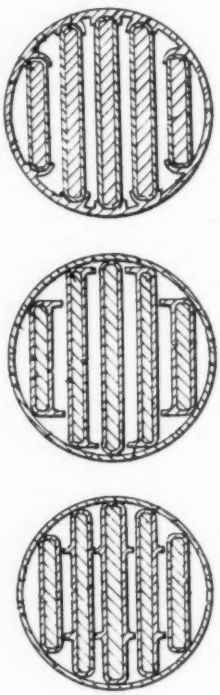
Applications are described for light-sensitive or photo-electric materials, photo-conductive and photo-voltaic cells, photo-transistors, rectifiers, point contact and junction transistors and as absorption filters for infra-red spectroscopy.

768,078 Improvements relating to fuel rod assemblies for nuclear reactors. Atomic Energy of Canada Ltd. Appn: March 31, 1954 (in Canada). Pubd: Feb 13, 1957

In all heavy water cooled nuclear reactors heretofore constructed the fuel rod assemblies have been composed of a cylindrical rod of fuel, normally uranium, encased in a tightly adhering sheath of suitable metal, usually aluminium, and usually an outer tube spaced from the sheath to leave a passageway through which the coolant is passed under pressure. In the formation of such assemblies one of the principal problems is the deformation to be expected in uranium metal under irradiation. Heretofore this problem had been dealt with by the use of a cylindrical form for the fuel rod so that the sheath would, even upon deformation, tend to adhere tightly to it, the tightness of the sheath being considered important to assure effective heat transfer. In addition, the fuel rod has generally been made up of short slugs rather than in one long piece.

In a high power pile the factor which governs the neutron flux obtainable is the maximum permissible temperature for the fuel. The disadvantage of the arrangement heretofore used is that it results in the minimum cooling surface per unit of volume of fuel, with the consequence that the neutron flux obtainable with the arrangement is severely limited by the maximum temperature which the fuel in the rods may be allowed to reach.

It has now been found that the cooling surface per unit of volume of the fuel, and hence the neutron flux obtainable, may be greatly increased with no resulting increased difficulty from deformation or from local overheating due to insufficient heat transfer from the fuel through the sheath. According to the invention the fuel is formed in thin strips, usually flat, which are enveloped in a tightly fitting thin pliable sheath of any of the usual sheathing metals, e.g. aluminium, zirconium or a zirconium-tin alloy or thin stainless steel. A plurality of these sheathed strips are arranged in a tube of circular cross-section in spaced parallel face-to-face relationship, each sheathed strip being of a width such that it is in contact with the tube along both its longitudinal edges. In this way



768,078 FUEL PLATES FOR D_2O REACTOR
Of the three described methods of supporting sandwich fuel plates inside a tube, the centre one is preferred, because the separating fins are easier to form

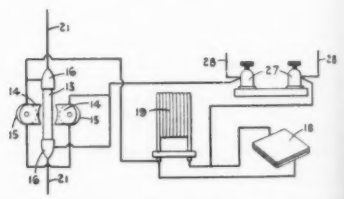
passages are formed along each face of each sheathed strip for the circulation of heavy water. Means are provided for restraining longitudinal bending of the sheathed strips. These means may be either projections on the inner surface of the tube embracing each longitudinal edge of each sheathed strip or longitudinal fins extending from the surface of certain of the strips across all the passageways between strips.

It has been found possible with a fuel rod assembly according to the present invention to obtain about seven times as high a neutron flux as is obtainable with a conventional assembly having the same volume of fuel.

763,062 A new apparatus for producing an electric current. H. V. Colman and R. W. D. Seddon-Gillespie Appn: June 22, 1953 Pubd: Dec 3, 1956

This is a secondary battery operating by the release of electrical energy from certain elements when bombarded by UHF radio waves. In the application described there is a quartz tube (13) mounted between the poles of an electromagnet (15). The tube is filled with a powdered mixture of compounds of Cd-112, P-31 and Co-59 which become radioactive and produce an electric current when treated with radio waves. The purpose of the magnet is to contain the alpha and beta particles which are produced in the reaction. Gamma activity is shielded by lead.

One end of the quartz tube contains powdered zinc and the other, powdered copper. These form the electrodes. The

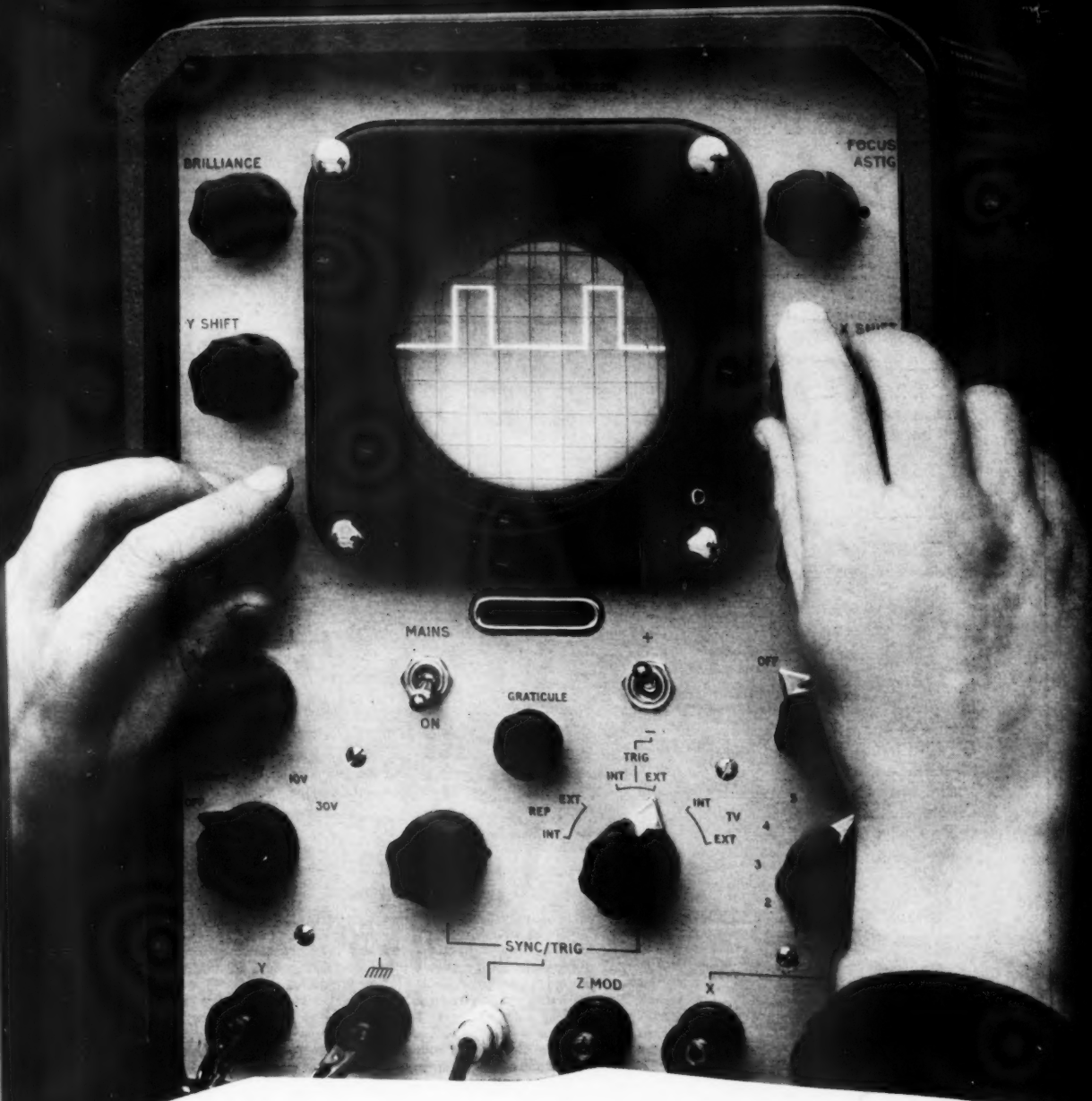


763,062 A RADIOACTIVE STORAGE BATTERY
13 Quartz tube
15 Electromagnet (fed from battery output)
16 Electrode end caps
18 Lead condenser
19 High frequency coil
21 Antennae
27 Output terminals

ends of the tube are sealed by brass caps (16) on which are mounted the receiving antennae (21) and which also collect the current.

The transmitter unit may be of any suitable type but is preferably crystal-controlled. The optimum energy release is obtained with a frequency of 300 mc/sec. It has been found that when fully charged with radioactivity the life of the battery is about one hour. When continuous operation is required, the transmitter has to be operated for about 15-30 secs every hour. With a quartz tube 45mm long and an inside diameter of 5mm and containing 30mg of the mixture, the estimated output is 100-110 volts at 10 amps.

It is claimed that the weight of the battery including shielding is only 25 per cent of that of any comparable known type of accumulator. The life of the mixture is said to be 70-80 years of constant use.



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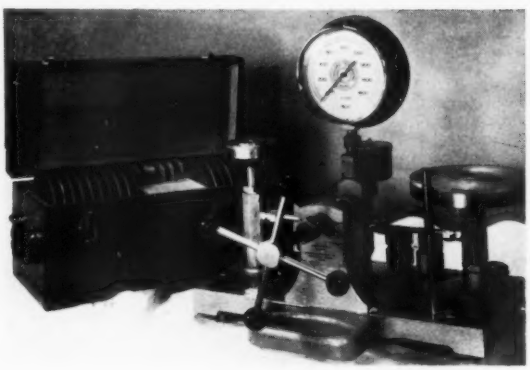

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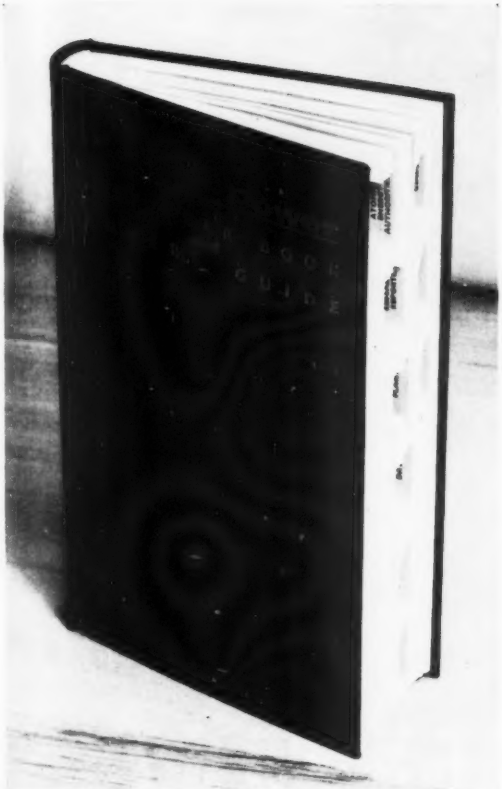

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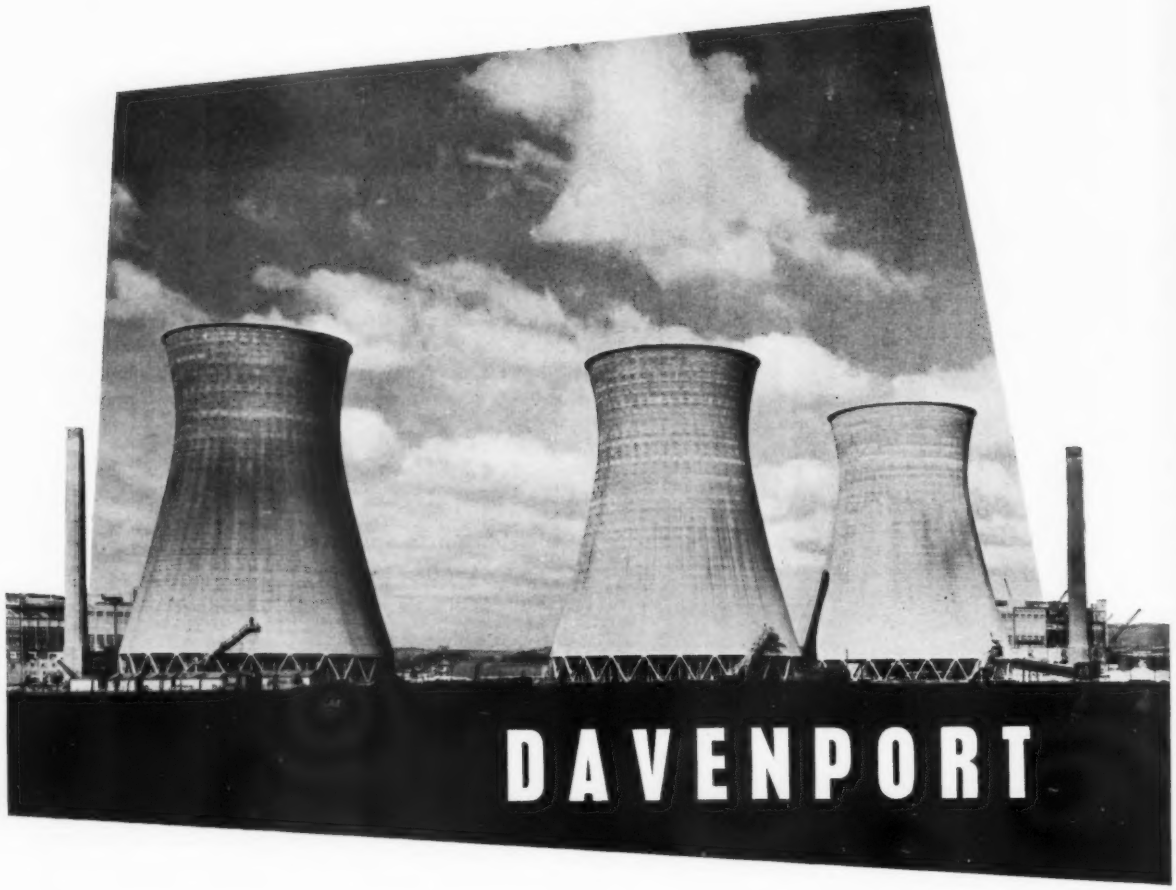

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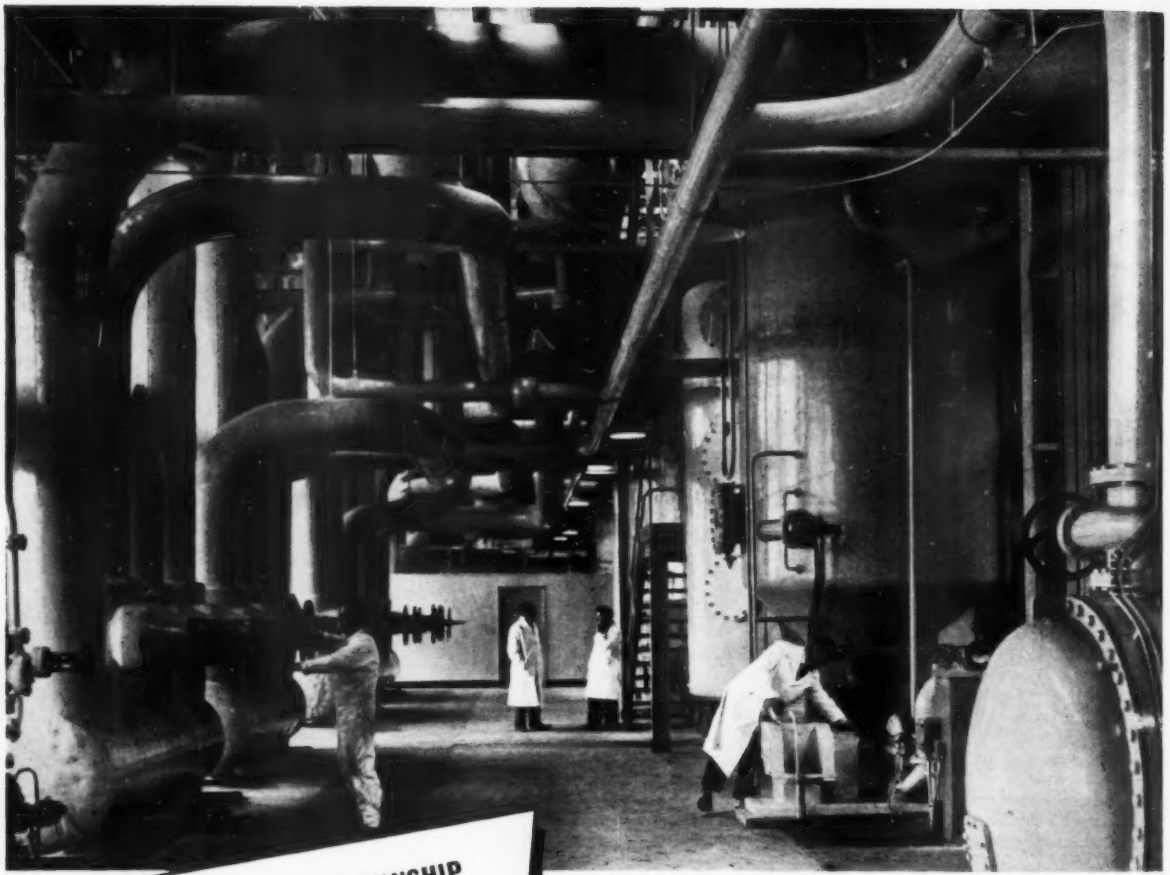

The basement of the turbine hall of Calder Hall A Station
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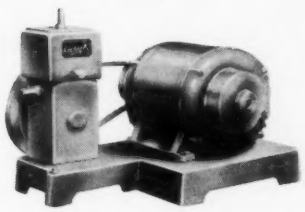

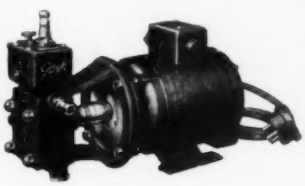

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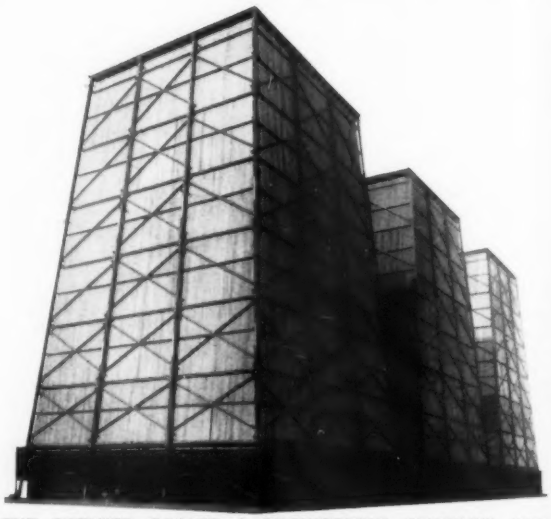

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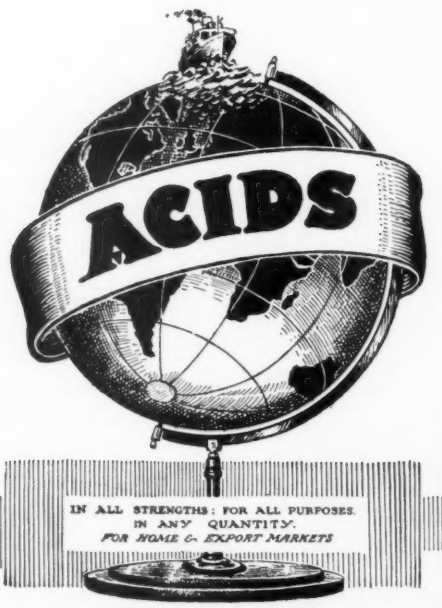

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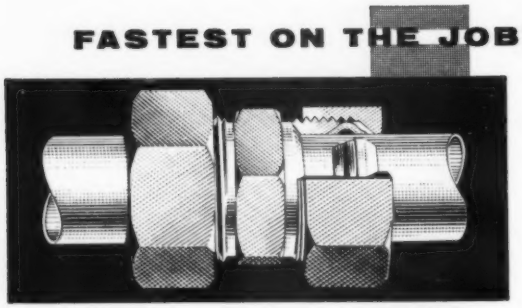

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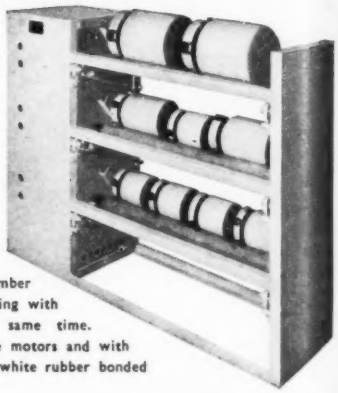

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INDEX TO ADVERTISERS

Acheson Colloids Ltd	February
AEI–John Thompson Nuclear Energy Co Ltd	February
Aerox Ltd	April
Allen, P. W. & Co	March
Amal Ltd	A27
Appleby & Ireland Ltd	A11
Atomwirtschaft	April
Bailey Meters & Controls Ltd	Inside Back Cover
Bailey, N. G. & Co Ltd	A25
Baldwin Instrument Co Ltd	January
Balfour Beatty & Co Ltd	April
Barnet Instruments Ltd	A38
Berk, F. W. & Co Ltd, Schori Division	January
Blakeborough, J. & Sons, Ltd	A35
BMB (Sales) Ltd	April
Board of Trade	February
British Ermeto Corp. Ltd	April
British Oxygen Gases Ltd	A3
British Thomson-Houston Co Ltd, The	April
Brooker, W. J. Ltd	A18
Bryce Electrical Construction Co Ltd	March
Butterfield, W. P. Ltd	A2
Cambridge Instrument Co Ltd	A31
Cape Building Products Ltd	A10
Carbon Dioxide Company, The	March
Carter, B. F. & Co Ltd	February
Central Electricity Authority	April
Chichester Rubber Co Ltd, The	April
Cinema-Television Ltd	A24
Cockburns Ltd	March
Cossor Instruments Ltd	January
Crossley Bros. Ltd	February
Darlington Insulation Co Ltd	168
Davenport Engineering Co Ltd	A42
Davidson & Co Ltd	A6
Dependable Relay Co	A49
Dowty Nucleonics Ltd	A39
Dynatron Radio Ltd	March
Ekco Electronics Ltd	170
Electric Furnace Co Ltd	April
Electrothermal Engineering Ltd	A26
Elliott Bros (London) Ltd	A31
Endecotts (Filters) Ltd	A46
Energia Nucleare	A34
Erhard, Johannes	A4
Ericsson Telephones Ltd	A32
Evers, D. H., Insurance	A22
Fielden Electronics Ltd	January
Firkins, G. & A. Ltd	A46
Fisher & Ludlow Ltd	April
Fleming Radio (Developments) Ltd	A43
Fulmer Research Ltd	A40
Gardners Radio	A23
Gardner, Henry & Co Ltd	A46
General Electric Co Ltd	A1
General Radiological Ltd	A16
Gordon, James & Co Ltd	February
Grazebrook, M. & W. Ltd	April
Hanovia	A23
Harvey, G. A. & Co (London) Ltd	February
Haworth, F. (A.R.C.) Ltd	April
Hayward Tyler & Co Ltd	A17
Head, Wrightson & Co Ltd	A48
Heather Filters Ltd	A26
Hilger & Watts Ltd	A28
Honeywell-Brown Ltd	A15
Howden, James & Co Ltd	Inside Front Cover
Humphreys & Glasgow Ltd	April
Imperial Chemical Industries Ltd.	A29
Industrial Exhibitions Ltd	A16
Isotope Developments Ltd	April
IV Pressure Controllers Ltd	A12
Johnstone, Archibald Ltd	March
Keith Blackman Ltd	April
Kodak Ltd	A44
Labgear (Cambridge) Ltd	April
Laboratory Apparatus & Glassblowing Co	April
Laing & Son, Ltd, John	April
Lake & Elliot Ltd	April
Lyons Ltd, Claude	March
Magnetic Valve Co Ltd	April
Mallinson, William & Sons Ltd	A27
Marston Excelsior Ltd	A5
McGraw-Hill Publishing Co Ltd	February
Martonair Ltd	A32
Metropolitan-Vickers Electrical Co Ltd	April
Mills Scaffold Co Ltd	April
Mitchell Engineering Ltd	Back Cover
Moler Products Ltd	April
Mollart Engineering Ltd	January
Morgan Crucible Co Ltd, The	April
Mullard Ltd	A33
Mullard X-Ray Division	A19
Munro & Miller Ltd	April
Murex Welding Processes Ltd	April
Nash & Thompson Ltd	A48
North British Chemical Co Ltd	A30
Nuclear Enterprises (GB) Ltd	A45
Nuclear Graphite Ltd	April
Nuclear Power Plant Co Ltd, The	February
Panax Equipment Ltd	A43
Pascall Engineering Co Ltd, The	A48
Philips Electrical Ltd.	Front Cover
Plessey Co Ltd	October
Powell Duffryn Carbon Products Ltd	A7
Premier Cooler and Engineering Co Ltd	A46
Pulsometer Engineering Co Ltd	A45
Pye Ltd (Industrial TV Division)	April
Pyrene Co Ltd, The	April
Racal Engineering Ltd	A28
Rawlplug Co Ltd, The	A9
Raytheon Manufacturing Co	April
RFD Co Ltd (Industrial Safety Division)	A30
Royal Photographic Society, The	A41
Sangamo Weston Ltd	April
Savage & Parsons Ltd	April
Shandon Scientific Co Ltd	February
Shaw-Petrie Ltd	April
Shell Chemical Co Ltd	A36
Shell Mex & BP Ltd	November
Silica Gel Ltd	A34
Simplifix Couplings Ltd	A48
Smith, J. & Sons (Clerkenwell) Ltd	A49
Solartron Electronic Group Ltd, The	A37
Southern Instruments Ltd	A13
Spencer Chapman & Messel Ltd	A47
Stewart Aeronautical Supply Co Ltd	A47
Sunvic Controls Ltd	April
Talbot Stead Tube Co Ltd	A20
Teddington Aircraft Controls Ltd	April
Thompson, John Ltd	April
Timeg Ltd	A45
Titanium Metal & Alloys Ltd	April
Unit Superheater & Pipe Co Ltd	February
Vokes Ltd	A14
Wandleside Cable Works Ltd	A8
Weir, G. & J. Ltd	April
Western Detail Manufacturers Ltd	A21
Wharton Crane & Hoist Co Ltd	April
Whessoe Ltd	January

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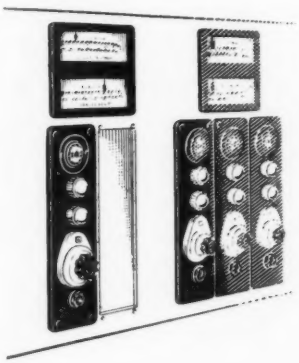

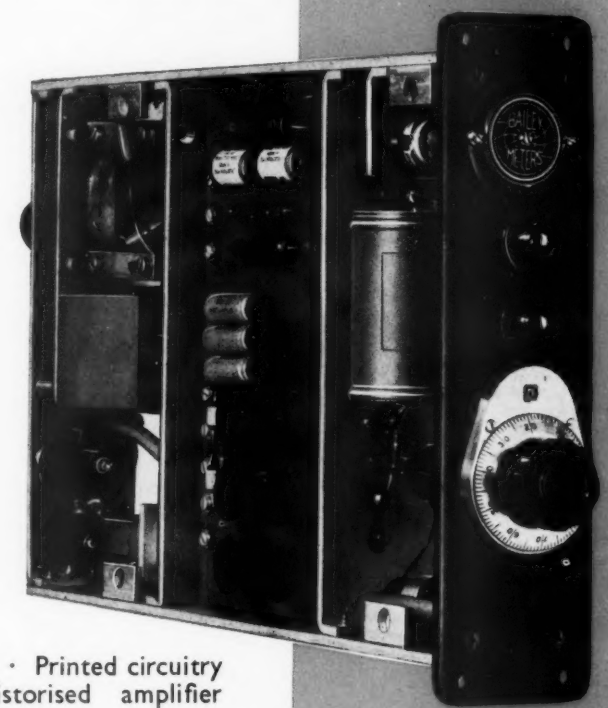

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Nuclear Power
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

ATOMIC POWER FOR PEACEFUL USE

For the *fourth time* . . . Mitchell's have been chosen to work on British Atomic Plants

1	*Chapelcross.* Mitchells are the main civil engineering contractors for this important new AEA nuclear power station. The contract, valued at £3½m., includes all buildings and cooling towers.	CHAPELCROSS
2	*Capenhurst.* Mitchells are installing pipework, process plant and equipment at this AEA plant. Six cooling towers are also being built by Mitchells.	CAPENHURST
3	*Springfields.* This contract is for pipework and other plant for the Atomic Energy Authority.	SPRINGFIELDS
4	*Dounreay.* Supply and installation of engineering equipment for the chemical laboratories associated with this new fast-breeder reactor in the north of Scotland.	DOUNREAY

Mitchells, co-operating with their American Associates AMF Atomics Inc, are also supplying complete nuclear power stations for export; they have already received an order for an atomic station from the largest power concern in the Ruhr.

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